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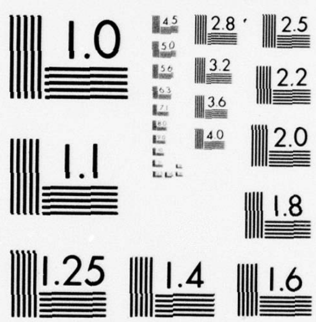

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WATER TREATMENT UNIT DEVELOPMENT FOR FIELD ARMY MEDICAL FACILITIES

TECHNICAL REPORT

by

M.K. Lee, P.Y. Yang,

and R.A. Wynveen

March, 1978

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Ft. Detrick, Frederick, MD 21701

Supported by

US Army Medical Research
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Ft. Detrick, Frederick, MD 21701

Contract DAMD17-76-C-6063

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A pilot plant of an integrated Water Processing System has been developed. The Water Processing System treats nonsanitary wastewaters of the U. S. Army field hospitals either for nonpotable reuse or for surface discharge to the environment and purifies natural fresh and brackish waters for potable use. The Water Processing System consists of four units: (1) a Water Treatment Unit, (2) a Water Purification Unit, (3) a UV/Ozone Oxidation Unit and (4) an Automatic

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Instrumentation Unit. This report describes the design, configuration and operation of the Water Treatment Unit. The primary objective of the Water Treatment Unit is to remove suspended solids and turbidity from hospital wastewaters.

The Water Treatment Unit consists of three unit processes: (1) equalization/prescreening, (2) ultrafiltration and (3) hypochlorination. The overall contaminant removal efficiencies projected for hospital composite wastewater are 99% for suspended solids and turbidity and 70 to 80% for total organic carbon and chemical oxygen demand. The Water Treatment Unit was sized to treat 4,120 gal of hospital wastewaters per 20-hour day at a product water recovery of 95%. The overall dimensions of the transportable Water Treatment Unit are 12 x 8.75 x 6.75 ft.

Life Systems, Inc.

ER-314-7-2

WATER TREATMENT UNIT DEVELOPMENT FOR FIELD ARMY MEDICAL FACILITIES

TECHNICAL REPORT

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Cleveland, OH 44122

for

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Ft. Detrick, Frederick, MD 21701

EXECUTIVE SUMMARY

American soldiers do not question the quality of the water that comes from the tap. They drink and shower daily without any suspicion. Limited sources of natural fresh water, together with the possibility of ground water poisoning by the enemy, make the reclamation of wastewater for reuse extremely vital to the operation of the combat unit and the Army field hospital in water deficient areas. In response to this need, the U.S. Army Medical Research and Development Command has been developing a wastewater reuse system for the field hospital. The system is called a Water Processing System. The interim objective is reuse of nonsanitary wastewater for nonpotable hospital requirements. The ultimate objective is reuse for potable and nonpotable requirements. A full-scale pilot plant of a Water Processing System was designed, built and delivered to the Army under Contract DAMD17-76-C-6063.

The Water Processing System has a nominal product water capacity of 3,500 gal per 20-hour day. The Water Processing System consists of four units: (1) a Water Treatment Unit, (2) a Water Purification Unit, (3) an Ultraviolet/Ozone Oxidation Unit and (4) an Automatic Instrumentation Unit. The objective of this report is to describe in detail the design, configuration and operation of the Water Treatment Unit.

There are two types of composite wastes in the nonsanitary wastewater produced in the field hospital. One is a hospital composite waste consisting of shower (51%), operating room (26%), kitchen (12%), laboratory (8%) and X-ray waste (3%). The other is a laundry composite consisting of 67% Type I (color-fast) and 33% Type II (woolens). In addition to the above wastes, the Water Processing System is to treat natural fresh or brackish water for potable use. The projected variations of the contaminant concentrations in the hospital wastewater are 50-1,000 mg/l for total organic carbon and suspended solids, 300-6,000 mg/l for chemical oxygen demand, 500-4,200 mg/l for total solids and 5-900 JTU for turbidity.

There are two modes of operation in the Water Processing System: Reuse Mode and Potable/Discharge Mode. In the Reuse Mode, the Water Processing System treats and purifies nonsanitary hospital wastewater for nonpotable reuse. In the Potable/Discharge Mode, it simultaneously treats those wastewaters for discharge to the environment while treating natural fresh or brackish water for potable use. The overall product recovery is at least 85% of inflow in the Reuse Mode and 90-95% in the Potable/Discharge Mode. The overall contaminant removal efficiencies are 98.9% for total organic carbon, 99.5% for chemical oxygen demand and 98.5% for total solids.

The primary objective of the Water Treatment Unit is to remove suspended solids from hospital wastewater. In the Reuse Mode, the Water Treatment Unit is a pretreatment unit for the Water Purification Unit, but in the Potable/Discharge Mode it operates as an independent unit to treat hospital wastewater for discharge to the environment. The overall contaminant removal efficiencies of the Water Treatment Unit for the hospital composite waste are approximately 99% for suspended solids and turbidity and 70 to 80% for total organic carbon and chemical oxygen demand.

The Water Treatment Unit consists of three unit processes: (1) equalization/prescreening, (2) ultrafiltration and (3) hypochlorination. The equalization/prescreening process separates gross suspended solids from the wastewater influent and equalizes time-varying hydraulic loading and concentration variations to result in a more uniform feed to the ultrafiltration process.

In the ultrafiltration process, suspended solids and some dissolved solutes with a molecular weight greater than about 15,000 are separated from the process water stream. The hypochlorination process is used to maintain 2 mg/l of free residual chlorine in the surface discharge water for disinfection. The Water Treatment Unit is to be operated 20 hours a day.

The Water Treatment Unit was designed to treat 4,120 gal of hospital wastewater per 20-hour day at a product recovery of 95%. The unique requirements for the Water Treatment Unit design are: (1) limited allowance on dimensions, weight and power consumption for transportation and field application; (2) automatic instrumentation and minimum maintenance for unskilled operators; and (3) pilot plant capabilities and semiautomatic instrumentation for performance evaluation and scientific data development.

The ultrafiltration process is the heart of the Water Treatment Unit. It is a membrane separation process in which a semipermeable membrane separates suspended solids and some dissolved solutes from permeable water. Due to the high contaminant concentration of suspended solids and total solids in wastewater, the permeate flux of the ultrafiltration membranes is relatively low. Thus, the flux is of prime concern in order to reduce volume, weight, power consumption and cost of the Water Treatment Unit. A commercial tubular membrane was selected due to its demonstrated performance on the Army hospital wastewater. The total surface area of 72 HFD membranes installed in the ultrafiltration assembly is 158 ft^2. The customized equalization/prescreening tank has a volume of 1,320 gal to absorb hydraulic fluctuation and to dampen the contaminant concentration variation. The hypochlorination unit consists of a 50 gal hypochlorite tank, a hypochlorite feed pump and static mixers. The overall dimensions of the transportable Water Treatment Unit are 12 x 8.75 x 6.75 ft. The unit is configured so all components are easily accessible.

Both automatic and semiautomatic instrumentations were incorporated into the Water Treatment Unit design to control and monitor the system performance. Only the semiautomatic instrumentation is described in this report. It is highlighted by five automatic fail-safe shutdown controls, 13 digital readout monitors, ten warning and alarm lights and 26 controls for pumps and valves.

FOREWORD

This study was conducted, as part of the Water Processing System pilot plant development, for the U. S. Army Medical Research and Development Command, Fort Detrick, MD, under Contract DAMD17-76-C-6063. The Program Manager was Dr. R. A. Wynveen. Technical effort was completed by Dr. M. K. Lee, Dr. P. Y. Yang, Dr. J. Y. Yeh, G. G. See and J. S. Davis.

Mr. W. J. Cooper and Maj. W. P. Lambert, Environmental Protection Research Division, U. S. Army Medical Bioengineering Research and Development Laboratory, Fort Detrick, MD, were the Technical Monitors of this program. We also wish to acknowledge the technical contributions, assistance and program guidance offered by Lt. Col. L. H. Reuter and Capt. B. W. Peterman.

Results of the pilot plant development program under Contract DAMD17-76-C-6063 have been published in six reports as follows:

Title	Report No.
Pilot Plant Development of an Automated, Transportable Water Processing System for Field Army Medical Facilities	ER-314-7-1
Water Treatment Unit Development for Field Army Medical Facilities	ER-314-7-2
Water Purification Unit Development for Field Army Medical Facilities	ER-314-7-3
Advanced Instrumentation Development for a Water Processing Pilot Plant for Field Army Medical Facilities	ER-314-7-4
UV/Ozone Oxidation Technology Development for Water Treatment for Field Army Medical Facilities	ER-314-7-5
Data Acquisition, Monitor and Control System Development for Field Army Medical Facilities	ER-314-7-6

The first report, ER-314-7-1, outlines in brief the overall program for the pilot plant development of the Water Processing System. The succeeding reports present further details on the subsystem developments of the Water Processing System pilot plant. The pilot plant consists of four subsystems: (1) a water treatment unit, (2) a water purification unit, (3) a UV/ozone oxidation unit and (4) an automatic instrumentation unit. This report describes development of the Water Treatment Unit.

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ACRONYMS

COD	Chemical Oxygen Demand
EP	Equalization/Prescreening
HC	Hypochlorination
JTU	Jackson Turbidity Unit
MUST	Medical Unit, Self-Contained, Transportable
O_3/UV	Ultraviolet-Activated Ozone Oxidation
RO	Reverse Osmosis
TOC	Total Organic Carbon
UF	Ultrafiltration
WPS	Water Processing System
WPU	Water Purification Unit
WTU	Water Treatment Unit

INTRODUCTION

The U. S. Army has a requirement to provide a mission-oriented medical treatment system which is designed and equipped to facilitate rapid establishment and disestablishment. This flexibility permits immediate response by medical support units to any tactical, environmental or geographical change for combat units. The mobile medical treatment system will provide a contamination-free and controlled environment in which medical, surgical and ancillary procedures and other supporting functions can be performed. The system has been called Medical Unit, Self-Contained, Transportable (MUST).(1)

A sufficient, reliable supply of water with good quality plays a significant role in the deployment of a MUST-equipped hospital into water-deficient areas. In order that tactical flexibility of the combat unit and the mobile field hospital should not be limited by fixed fresh water sources, the U. S. Army Medical Research and Development Command (USAMRDC) has been developing a wastewater treatment and purification system for the MUST hospitals. The system is called a Water Processing System (WPS). The interim objective is reuse of nonsanitary wastewaters for nonpotable hospital requirements. The ultimate objective is reuse for potable and nonpotable requirements.

A full-scale pilot plant of the WPS has been designed and built by Life Systems, Inc. (LSI) under Contract DAMD17-76-C-6063 with the USAMRDC. The WPS has a nominal product water capacity of 3,500 gal per 20-hour day. The objective of the development program was to:

1. Design, fabricate, check out, deliver and start up a fully-functional WPS Pilot Plant.

2. Design, fabricate, test, install, start up and debug a Data Acquisition, Monitor and Control System.

3. Provide technical support to insure the operability of the WPS Pilot Plant.

The WPS Pilot Plant consists of four subsystems: (1) a Water Treatment Unit (WTU), (2) a Water Purification Unit (WPU), (3) a UV/Ozone Oxidation (O_3/UV) Unit and (4) an Automatic Instrumentation Unit.

The purpose of this report is to describe the design, configuration and operation of the WTU. This report is intended to be supplementary to LSI Report, ER-314-7-1, entitled, "Pilot Plant Development of an Automated, Transportable Water Processing System for Field Army Medical Facilities."

WATER PROCESSING SYSTEM

As shown in Table 1 there are two modes of WPS operation. In the Reuse Mode (Mode 1) the WPS treats and purifies nonsanitary hospital wastewaters for nonpotable reuse. In the Potable/Discharge Mode (Mode 2) it simultaneously treats those same wastewaters for discharge to the environment while treating

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(1) References cited in parentheses are listed at the end of this report.

TABLE 1 OPERATIONAL MODES OF THE WATER PROCESSING SYSTEM

Operational Mode	Function	Product Recovery
1. Reuse	• Treatment and Recycle of Nonsanitary Hospital Wastewaters	85%
2. Potable/ Discharge	• Treatment of Natural Fresh and Brackish Waters for Potable and Nonpotable Use	90%
	• Treatment and Discharge to the Environment of Nonsanitary Hospital Wastewaters	95%

natural fresh or brackish water for potable use. The overall recovery of product water is at least 85% of inflow for Mode 1 and 90-95% for Mode 2. The WTU has been designed to meet the objective in the Reuse Mode.

Figure 1 is a block diagram of the Reuse Mode. Nonsanitary hospital wastewaters (such as operating room, kitchen, X-ray, laboratory, shower and laundry) are fed to the Equalization/Prescreening (EP) process in which gross suspended solids are removed. In addition, the EP process equalizes time-varying hydraulic loading and concentration variations to result in a more uniform feed to the Ultrafiltration (UF) process. In the UF process, the suspended and dissolved solutes with a molecular weight greater than 15,000 are separated to minimize the fouling and maintenance of the Reverse Osmosis (RO) membranes. The function of the RO process is to remove most of the dissolved organics with a medium molecular weight of 150 to 15,000. The residual low molecular weight organic solutes are finally oxidized in the O_3/UV process to meet the water quality specifications for nonpotable use: 5 mg/l total organic carbon (TOC) and 10 mg/l chemical oxygen demand (COD), or less. The Hypochlorination (HC) process is used to maintain 5 mg/l free-residual chlorine in the product reuse water.

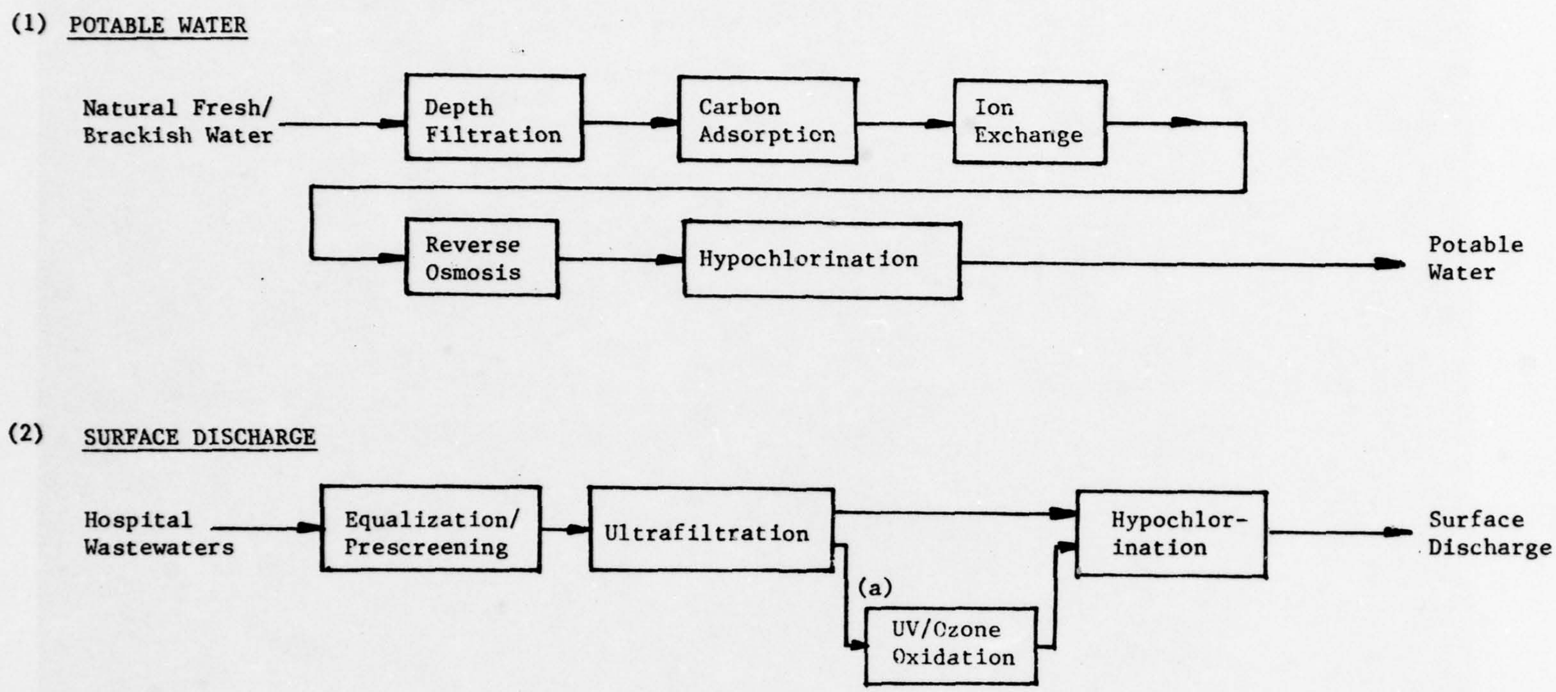
The typical distribution of TOC, COD and total solids concentrations for hospital composite wastewater is also shown in Figure 1. The numbers in parentheses are the typical rejection percentages for each unit process. The overall contaminant removal rates projected are 98.9% for TOC, 99.5% for COD and 98.5% for total solids.

Figure 2 is a block diagram of the Potable/Discharge Mode. The WPS performs two separate, independent functions simultaneously: (1) potable water production from natural fresh or brackish water and (2) hospital wastewater treatment to protect the environment from toxic waste discharge. A total of eight unit processes are included in both treatment trains. The Ion Exchange (IE) and RO processes are the main stages of the potable water treatment, while the UF process is the heart of hospital wastewater treatment for discharge. Each train has its own HC unit. The O_3/UV process in the surface discharge train is used only for certain waste streams with high organic loading, such as kitchen, laboratory, X-ray and composite wastes.

The WPS is a fully automated, integrated water treatment system which fulfills several functional requirements as described above. Figure 3 is a flow diagram of the WPS. The selection of unit processes and flow paths is determined by pressing proper mode and water source switches on the master control panel. The WPS employs one of the most advanced instrumentation concepts which is highlighted by minicomputer-based automatic control and monitor and by the capability of the fault detection/isolation and performance trend analysis. For pilot plant testing a number of flexibilities such as semiautomatic instrumentation and manual overrides for major components were incorporated. The WPS can be operated at a remote terminal with all of its control, monitor and data acquisition benefits.

	TOC (mg/l)	COD (mg/l)	Total Solids (mg/l)
Nonsanitary Hospital Wastewaters	50-1,000[2]	300-6,000[2]	500-4,200[2]
Equalization/ Prescreening (EP)			
	463	1,875	1,240[2]
Ultrafiltration (UF)	(73%)	(76%)	(26%)
MW ≤15,000	125	450	918
Reverse Osmosis (RO)	(76%)	(76%)	(98%)
MW ≤150	30[3,4]	108[3,4]	18
UV-Ozone Oxidation (O_3/UV)	(≥84%)	(≥91%)	--
	≤5	≤10	--
Hypochlorination (HC)	--	--	--
Nonpotable Reuse Water	≤5	≤10	--
Total Removal %	(≥98.9)	(≥99.5)	(≥98.5)

FIGURE 1 UNIT PROCESSES INVOLVED IN REUSE MODE



(a) For wastes with high organic loading such as kitchen, lab, X-ray and composite.

FIGURE 2 UNIT PROCESSES INVOLVED IN POTABLE/DISCHARGE MODE

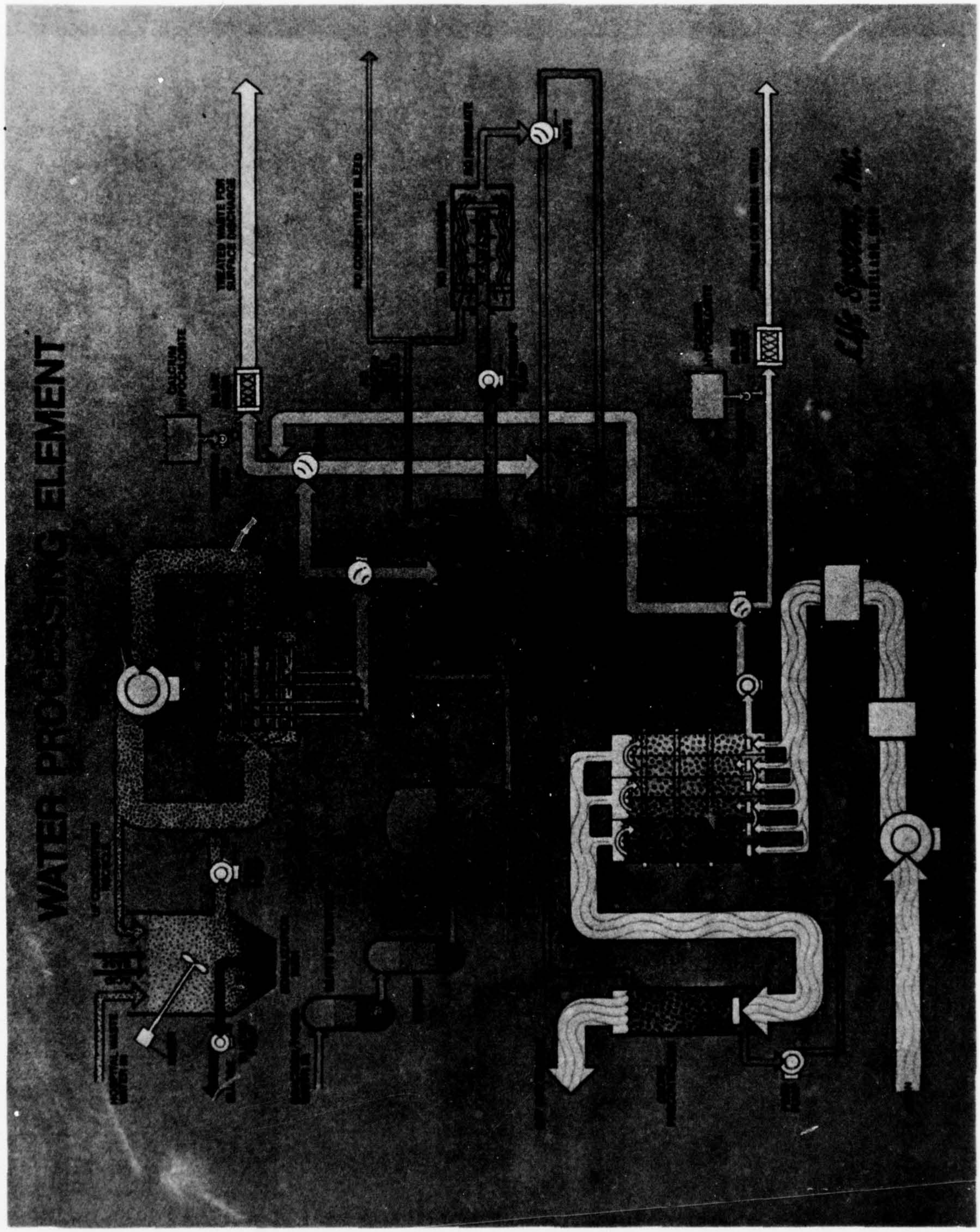


FIGURE 3 FLOW DIAGRAM OF WATER PROCESSING SYSTEM PILOT PLANT

WATER TREATMENT UNIT

The primary objective of the WTU is to remove suspended solids from hospital wastewaters in order to reduce the fouling and maintenance of the RO membranes. In the Reuse Mode, the WTU is a pretreatment unit for the WPU, but in the Potable/Discharge Mode it operates as an independent unit to treat hospital wastewaters for discharge to the environment.

The projected variations of the contaminant concentrations in hospital wastewaters are 50-1,000 mg/l for TOC and suspended solids, 300-6,000 mg/l for COD, 500-4,200 mg/l for total solids and 5-900 JTU for turbidity.[2,5] The overall contaminant removal efficiencies projected for the hospital composite wastewater are 99% for suspended solids and turbidity and 70 to 80% for TOC and COD.

Process Description

Figure 4 is a flow schematic of the WTU. Hospital wastewaters from Sources A (shower, operating room and laundry wastes) and B (hospital composite, laboratory, X-ray, kitchen and other unknown wastes) are fed to the EP tank where hydraulic loading and concentration variations are equalized to result in a more uniform feed to the UF membranes.

The wastewater is then pumped through a 40-mesh basket strainer and a heat exchanger to the UF membrane assembly in which suspended solids and other contaminants are separated from the process water stream. The permeate stream of the UF assembly is finally fed to a WPU in the Reuse Mode, or to an O_3/UV Unit for Wastewater Source B in the Discharge Mode, or to a HC Unit for Wastewater Source A.

The EP tank is divided into four compartments: (1) a bad actor tank, (2) a mixing zone, (3) a clarifier section and (4) a UF feed tank. All wastewaters except laboratory waste are collected into the mixing compartment where pH is adjusted to about eight by adding either an acid (sulfuric acid (H_2SO_4)) or a base (sodium hydroxide (NaOH)). The laboratory waste, which is high in refractory organic concentration, is separately collected and equalized in the bad actor tank before being allowed to overflow to the mixing compartment. The four compartments are interconnected through holes on the dividing walls. Sludge formed and accumulated at the bottom of the EP tank is removed automatically once every day during the four-hour maintenance period. The sludge pump is programmed to operate for 12 minutes at a pumping rate of 11 gpm.

The UF feed pump feeds the wastewater to the UF assembly circulation loop at the rate of approximately 20 gpm. The circulation pump feeds both the recycle and the feed water to the UF membranes at the rate of 270 gpm. The UF membrane assembly has a total of 72 HFD tubular membranes. The flow rate of UF permeate varies with the operating conditions and the wastewater characteristics. Only the wastewater temperature is controlled by a heat exchanger to maintain the permeate flux above the required minimum of 3.26 gpm. A small portion of the recycle flow is bled to the EP tank to maintain a constant recycle flow rate.

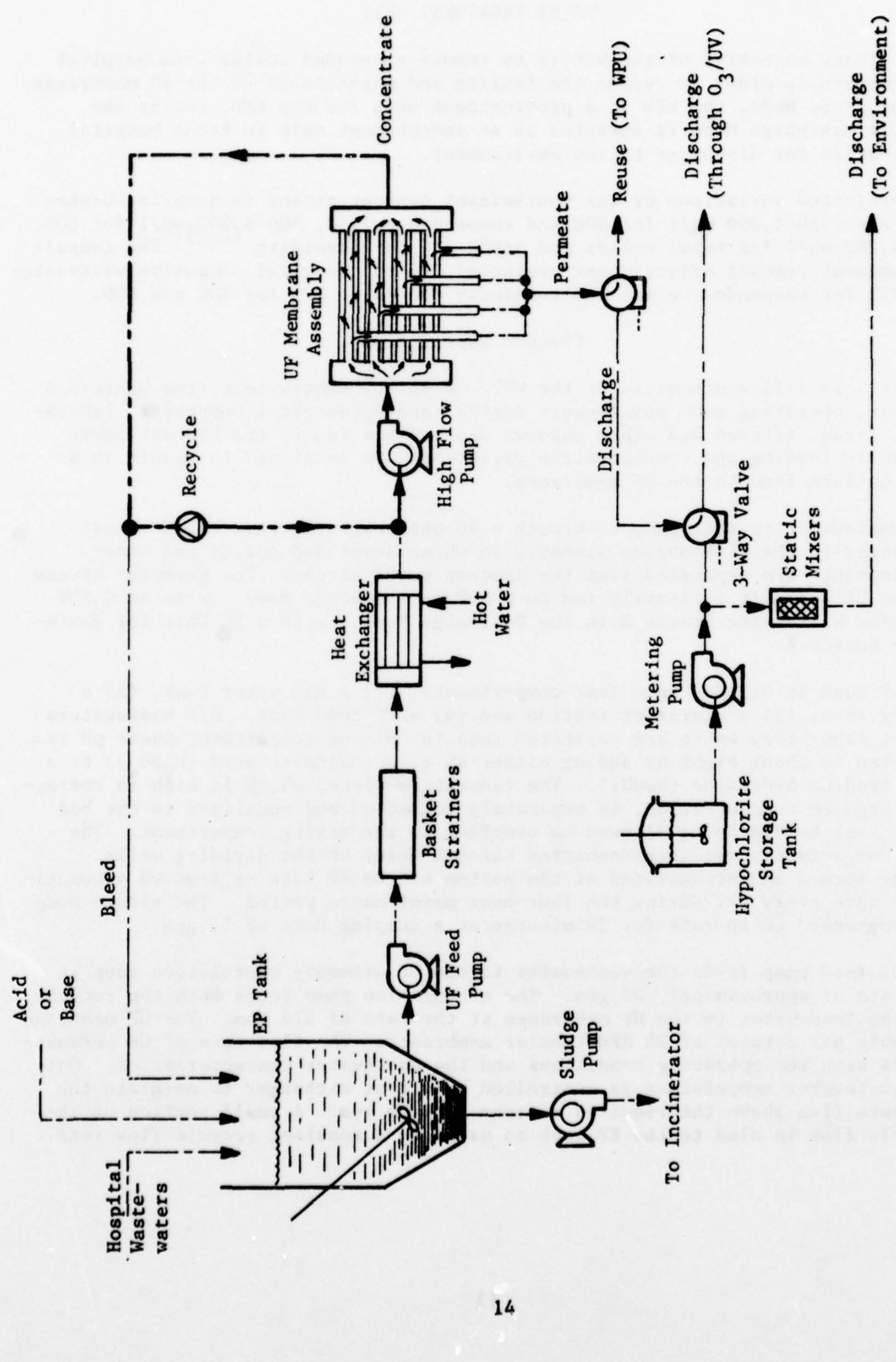


FIGURE 4 FLOW SCHEMATIC OF WATER TREATMENT UNIT

The function of the HC Unit is to maintain 2 mg/l free-residual chlorine in the discharge water for disinfection. In order to maintain the required chlorine level, 7% calcium hypochlorite ($Ca(OCl)_2$) solution stored in a 50 gal polyethylene tank is metered by a metering pump and mixed with the UF permeate in static mixers. The flow rate of the hypochlorite is automatically controlled in a feed-forward mode by means of an upstream flow sensor and a pump control logic.

Hardware Description

Figures 5 and 6 are photographs of the WTU. Figure 5 shows the UF membrane assembly, a high flow pump for circulation of UF recycle and feed flow, a sludge pump for removal of settled material in the EP tank, the HC Unit and the semiautomatic instrumentation panel.

The UF membrane assembly contains nine modules installed in parallel. Each module consists of eight tubular membrane elements in series. The membrane element is 1.0 in dia. x 10 ft long with an active surface area of 2.2 ft^2. The total active surface area of the UF membrane assembly amounts to 158 ft^2.

Figure 6 shows the EP tank, the valve plane and the interface panel. All inputs and outputs of the WTU (mechanical and electrical) go through the interface panel which is shown in Figure 7. The EP tank has a total wet volume of 176 ft^3. The tank is fabricated of fiberglass. The overall dimensions of the WTU are 12 x 8.75 x 6.75 ft. The unit is configured so all components are easily accessible.

The semiautomatic instrumentation panel shown in Figure 8 is highlighted by five automatic fail-safe shutdown controls, 13 digital readout monitors, ten warning and alarm lights, and 26 controls for pumps and valves.

Operation

The WTU can be operated in three modes: (1) Stand Alone, (2) Integrated Semiauto and (3) Integrated Auto. In the Stand Alone mode, the WTU operates as a self-contained unit to treat hospital wastewaters (Source A) for surface discharge. In the Integrated modes, the WTU operates as a pretreatment unit in the WPS which consists of the WTU, the WPU and the O_3/UV Unit.

In the Stand Alone mode the only connection needed is system power. With both main and pump power turned on, operation of the unit is initiated by pressing the Reset button on the front panel. Before turning on the prime movers, all valve switches should be placed in the proper positions for surface discharge through the HC unit. The EP tank mixer, UF feed and high flow pumps, and the HC pump are then turned on sequentially by setting corresponding toggle switches to the ON positions. As flow develops these switches should be placed in their AUTO positions for the automatic shutdown controls to function. Finally, the UF flow control valve and the HC chlorine dosage control are adjusted to give a concentrate flow rate of 270 gpm and a free-chlorine level of 2 mg/l. Operation of the WTU in the Integrated Semiauto mode is basically the same as that in the Stand Alone mode and is not discussed here.

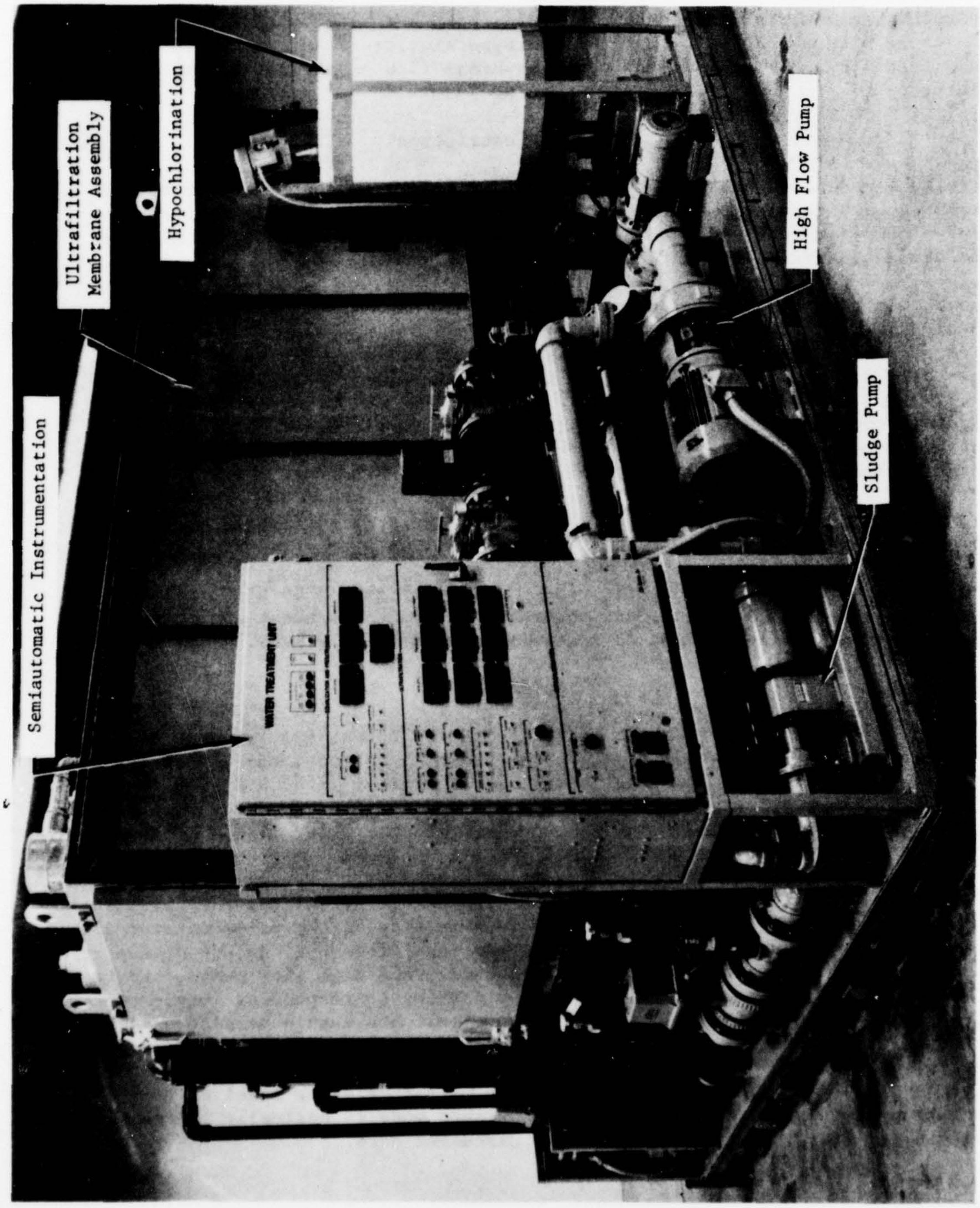


FIGURE 5 WATER TREATMENT UNIT, FRONT VIEW

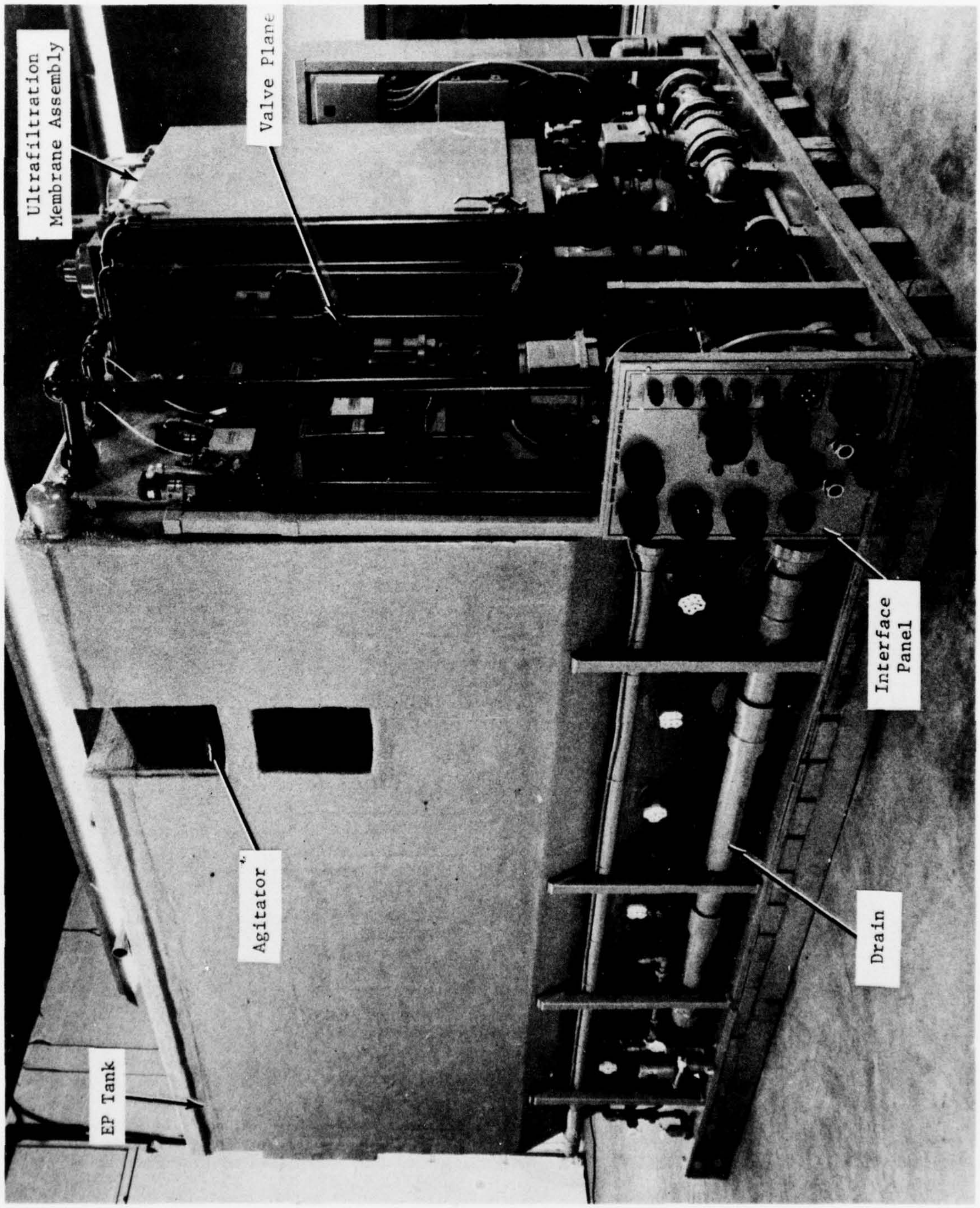


FIGURE 6 WATER TREATMENT UNIT, REAR VIEW

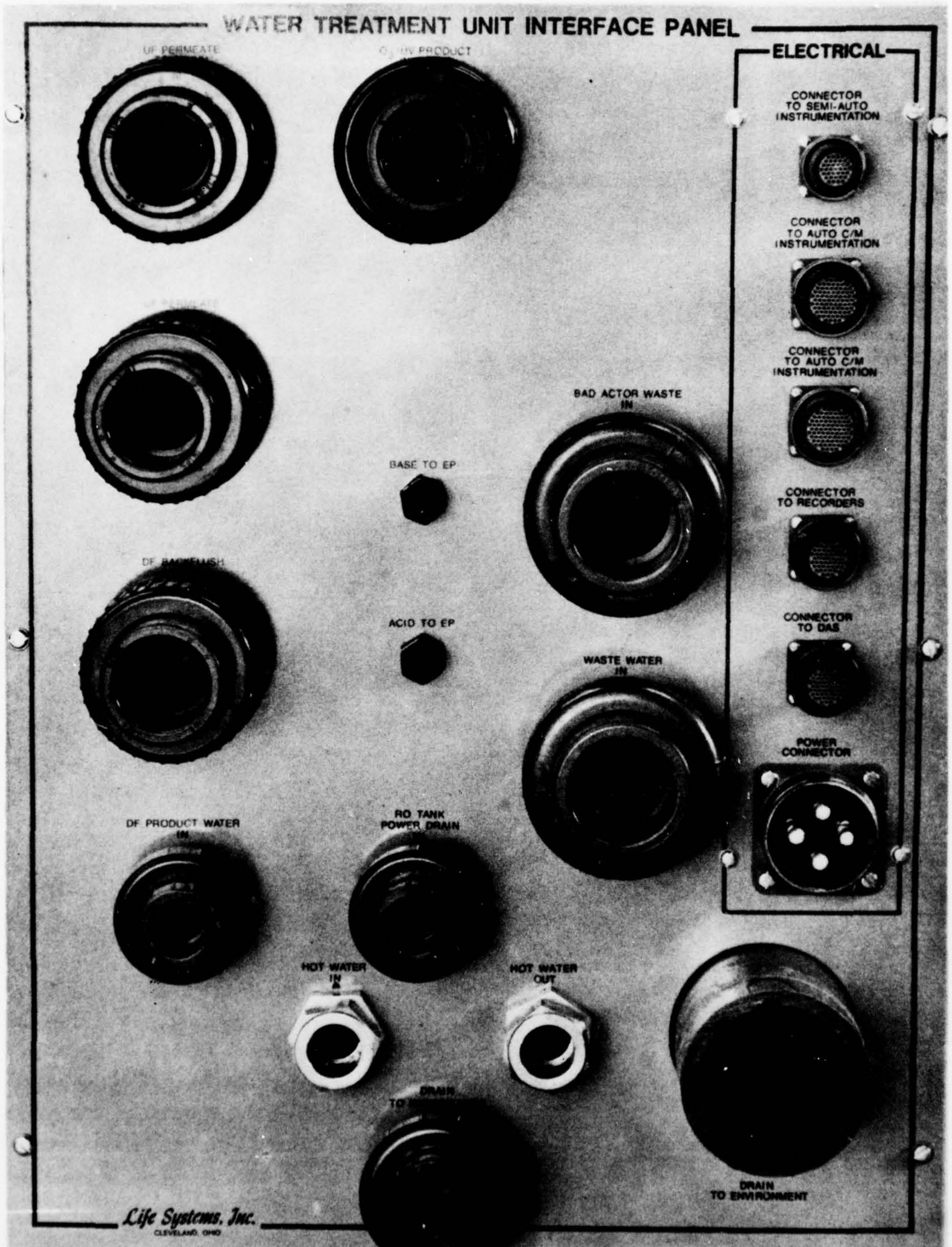


FIGURE 7 INTERFACE PANEL OF WATER TREATMENT UNIT

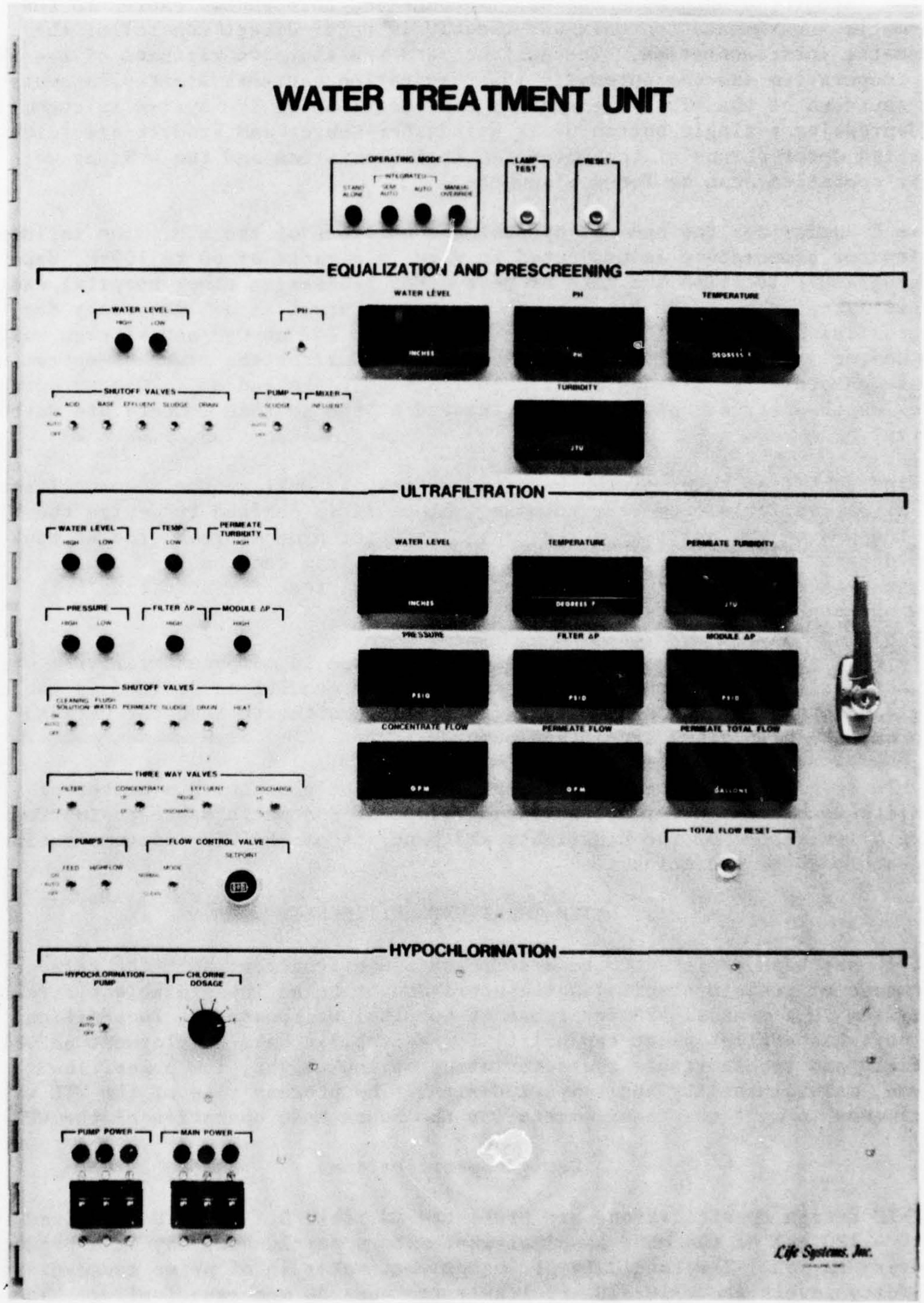


FIGURE 8 SEMIAUTOMATIC INSTRUMENTATION PANEL OF WATER TREATMENT UNIT

In the Integrated Auto mode the WTU is connected through two cables to the Automatic Instrumentation Unit and the WTU is under direct control of the automatic instrumentation. The switches and the shutdown circuits of the WTU are inoperative and the automatic instrumentation controls startup, operation and shutdown of the WTU. The startup and operation of the system is accomplished by depressing a single button after Wastewater Source and Product are selected. Detailed descriptions of the automatic instrumentation and the WPS, as well as their operation, can be found elsewhere.[6,7]

Table 2 summarizes the nominal operating conditions of the WTU. The influent wastewater temperature is projected to vary in a range of 60 to 109 F, depending on geographic location and time of year. For processing other hospital wastewaters except shower and kitchen, temperature control is not necessary due to the sufficient fluxes of UF membrane permeates. For shower and kitchen wastes, the heater is turned on approximately five hours after the start of operation. The temperature is raised gradually to 125 F near the end of a 20-hour operation. Other wastewaters are planned to be treated at the ambient temperature without control.

The influent flow rates of the hospital wastes, as well as their compositions, are highly variable from hour to hour. Since it is desired to design the WTU and the WPS on the basis of a reasonably constant process rate, the EP tank should have reserve water to prevent the system from running dry. The initial charge of 400 to 800 gal is projected to be sufficient for absorbing both flow and concentration variations.

The WTU is protected from catastrophic damages due to component failures or any abnormal operating conditions. As any alarm conditions defined in Table 3 develop, automatic shutdown controls instantly deactivate both the UF feed pump and the high flow circulation pump.

The WTU is a highly versatile, transportable pilot plant with a number of benefits incorporated for scientific development and performance evaluation. Table 4 lists some of the highlights and benefits of the WTU instrumentation for each mode of operation.

WATER TREATMENT UNIT DESIGN

The WTU has been designed to be a self-contained treatment unit for safe discharge of certain hospital wastewaters and to be an integratable pretreatment subsystem in a central WPS for reuse of hospital wastewaters. In addition, the unit has a pilot plant capability for scientific data development as well as field and transportable characteristics of low weight, low power, low volume, maintainability and compact design. The process rate of the WTU was determined to meet the requirements for the Reuse Mode operation of the WPE.

Design Specifications

The WTU design specifications are presented in Table 5. The WTU was sized to treat 4,120 gal of the MUST hospital wastewaters per 20-hour day at a product recovery of 95%. The turbidity of the product water is of prime concern since turbidity levels above 10 JTU are likely to cause RO membrane fouling. The

TABLE 2 NOMINAL OPERATING CONDITIONS
OF THE WATER TREATMENT UNIT

Operating Temperature, F	
• Shower and Kitchen wastes	68 to 125
• Other wastewaters	Ambient
Operating Pressure, psia	65
Concentrate Recycle Flow Rate, gpm	250
UF Feed Flow Rate, gpm	20
Wastewater Feed	
• Source: A	Shower, operating room, laundry
B	Hospital composite, lab, X-ray, kitchen
• Flow Rate, gal/day	4,940
gpm	3.43
• Temperature, F	60 to 110
• pH	2.7 to 10.5
• Turbidity, JTU	5 to 900
Product Water	
• Flow Rate, gal/day	4,695
gpm	3.26
• Temperature, F	68 to 125
• pH	8.0 to 8.5
• Turbidity, JTU	~10
Sludge Removal per Day, gal	132
Chlorine Level in Discharge Water, mg/l	2
Initial Charge to EP Tank, gal	400 to 800
Operating Time, hr/day	20

TABLE 3 SHUTDOWN DEFINITION AND INDICATION

No.	Parameters	Alarm Condition	Alarm Lamp
1	UF Water Level	≤16 in	UF Water Level Low
2	UF Pressure	≤10 psig	UF Press Low
3	UF Pressure	≥60 psig	UF Press High
4	UF Module Delta P	≥40 psig	UF Module Delta P High
5	UF Permeate Turbidity	≥10 JTU	UF Permeate Turbidity High

TABLE 4 HIGHLIGHTS/BENEFITS OF THE WTU INSTRUMENTATION

Highlights/Benefits	Operating Mode: Stand Alone	Operating Mode: Integrated Semiauto	Operating Mode: Integrated Auto
CONTROLS:			
• Minicomputer-based Automatic Instrumentation			X
• A Single Button Startup			X
• Automatic Shutdown Controls in Case of Emergency	X	X	X
• Automatic pH Control	X	X	X
• Automatic Sludge Removal			X
• Automatic Temperature Control	X	X	X
• Automatic Feed-Forward Control of Hypochlorination	X	X	X
• Remote ON/OFF CONTROL		X	X
• Remote CONTROL			X
• Automatic Cleaning of UF Membranes			X
MONITORS:			
• Written Communication between Operator and the System			X
• Fault Detection/Isolation and Performance Trend Analysis			X
• Remote Monitoring			X
• Digital Readouts	X	X	

TABLE 5 WTU DESIGN SPECIFICATIONS

Max. Dimensions (L x W x H), ft	12 x 8.75 x 6.75
Max. Dry Weight, lb	6,500
Max. Power, kW	30 for Total WPS
Wastewater Source	MUST Hospital Wastes
Treatment Capacity, gal/day	4,120
Product Capacity, gal/day	3,900
Overall Product Recovery, %	$\geq$95
Influent Water Quality	See Appendix 1
Effluent Water Quality	
Turbidity, JTU	$\leq$ 10
pH	5 to 9
Free Chlorine for Discharge Water, mg/l	$\geq$ 2
Operating Time, hr/day	20
Instrumentation	Semiauto and Auto

discharge water must have 2 mg/l free-available chlorine for disinfection. The WTU is to be operated 20 hours per day.

The unique requirements for the WTU design are: (1) limited allowance on dimensions, weight and power consumption for transportation and field application; (2) automatic instrumentation and minimum maintenance for unskilled operators; and (3) pilot plant capabilities and semiautomatic instrumentation for performance evaluation and scientific data development.

Wastewater Characteristics

Two types of wastes in the nonsanitary wastewaters are produced from the MUST hospital. One is a composite waste consisting of shower (51%), operating room (26%), kitchen (12%), laboratory (8%), and X-ray waste (3%). The other type is laundry waste consisting of 67% Type I (color fast) and 33% Type II (woolens). The WTU treats both types of wastes separately.

Appendix 1 lists the compositions of simulated MUST hospital wastewaters.[8] In reality, the flow rate and composition of the individual waste stream are expected to vary substantially from day-to-day as well as from hour-to-hour. A simplified flow schedule for the composite waste has been developed[8] and is presented in Figure 9. The projected organic composition of the WTU effluent for the hospital composite wastewater is shown in Table 6.

Ultrafiltration Membrane Characteristics

Ultrafiltration is a membrane separation process in which a semipermeable membrane separates suspended solids and some dissolved solutes from permeable solvent. The separation occurs either by the sieving mechanism or due to the difference in the mass transfer rates through the membrane. Ultrafiltration is carried out at reasonably low pressures, typically less than 150 psia. The process has been used successfully for the treatment of a number of industrial wastewaters.

Performance of a UF membrane is usually characterized by its solute rejection (R_m) and by the permeate flux (J_p). The rejection of a solute by a membrane may be defined as:

$$R_m = 1-C_p/C_f \qquad (1)$$

where C_p and C_f are the solute concentrations in the permeate stream and the feed water, respectively. The concentration of a solute in the permeate stream, C_p, often depends on the feed concentration, C_f, and can be related by simple functions of the form:[9]

$$C_p = kC_f^n \qquad (2)$$

where k is a constant and n ≥0. A value of n = 0 indicates constant permeate quality and n = 1 indicates constant rejection independent of the feed concentration.

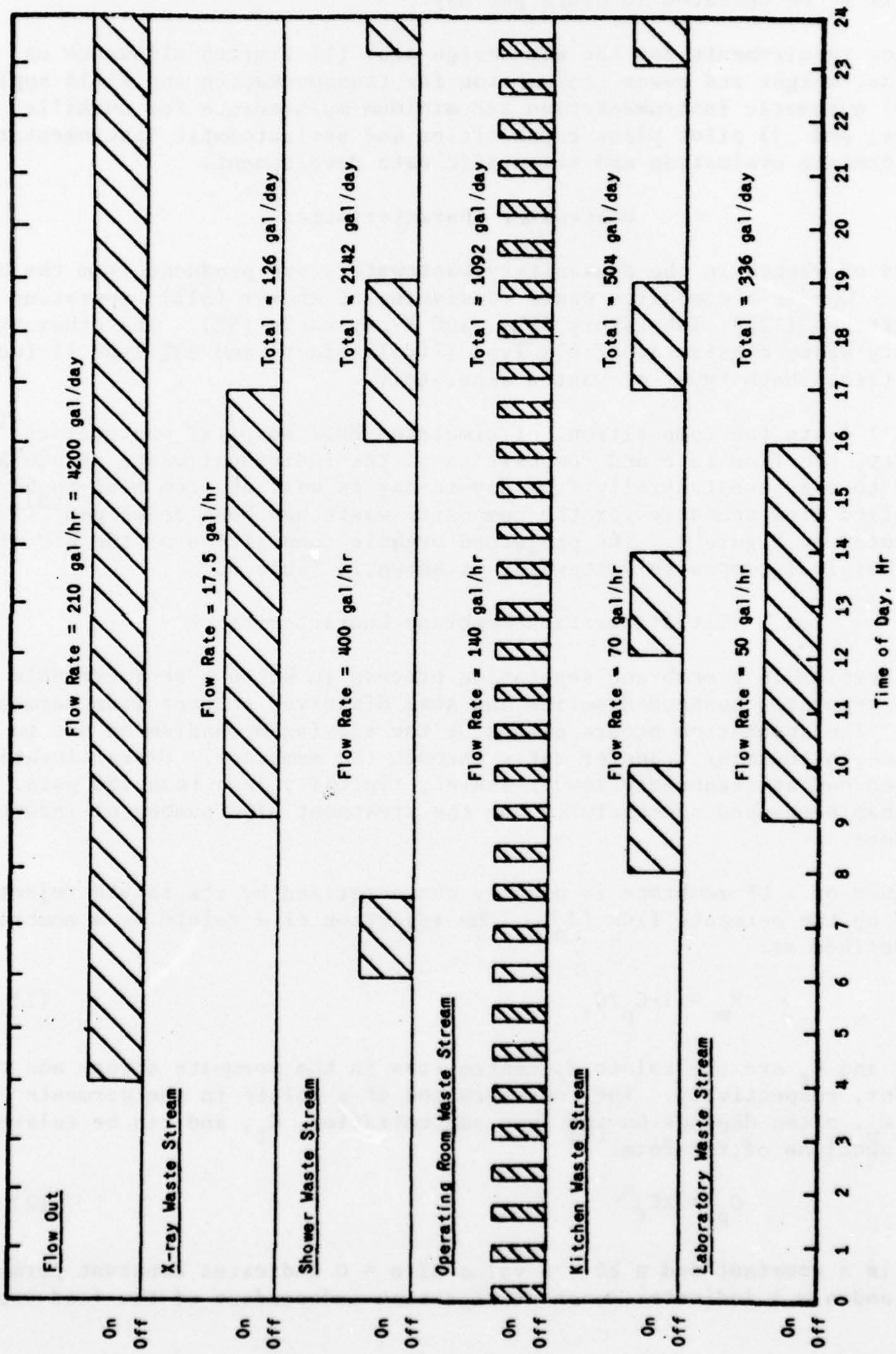


FIGURE 9 SIMPLIFIED FLOW SCHEDULE FOR THE MUST HOSPITAL COMPOSITE WASTE

TABLE 6 ESTIMATED ORGANIC COMPOSITION OF HOSPITAL COMPOSITE ULTRAFILTRATION PERMEATE

Components	Concentration
Methanol	29.8 μl/l
Acetone	6.3 μl/l
Acetic acid	3.4 μl/l
Diethyl ether	0.6 μl/l
N,N-Diethyl-m-toluamide	0.8 mg/l
Ethanol	0.5 μl/l
Oleic acid	0.5 μl/l
Phenol	1.3 mg/l
Urea	18.0 mg/l
Kodak X-Omat Developer	942 μl/l
Kodak X-Omat Fixer	942 μl/l

The accumulation of solutes on the membrane surface (known as concentration polarization) significantly affects the permeate flux. In the absence of concentration polarization the permeate water flux of the UF membrane, J_p, can be related to the pressure differential across the membrane, delta P:

$$J_p = \frac{K(\Delta P)}{\mu\sigma} \tag{3}$$

where m = viscosity of wastewater
w = membrane thickness, and
K = permeability of the membrane.

As concentration polarization develops, the permeate flux declines substantially and is controlled by the gel-layer mass transfer. Under such circumstances the pressure differential has an insignificant effect on the flux and the flow velocity plays an important role on the gel-layer mass transfer. The effects of the pressure differential and the flow velocity on the permeate flux are qualitatively shown in Figure 10. For laminar flows the flux is proportional to the one-third power of the flow velocity.[10,11]

System Design

Modular membrane systems can be designed to operate in one of several process configurations, i.e., semibatch, once-through continuous, recycle-and-bleed continuous, stages in series, stages in parallel, etc. Three common system designs are shown in Figure 11.

In the semibatch operation (Figure 11(a)), the feed tank is charged intermittently with wastewater influent while the UF permeate is continuously withdrawn. The concentrate stream is recycled back to the feed tank and sludge is intermittently removed from the bottom of the feed tank. There are three major advantages to this type of operation:

1. Feed flow rate can be easily adjusted to control membrane fouling and concentration polarization while maintaining a constant product recovery.

2. A very high product recovery can be obtained without much risk of membrane fouling.

3. The feed concentration builds up slowly to result in higher flux and rejection.

The disadvantages of this mode are requirements for intermittent draining of the feed tank and for product control, if needed. Both the product flow rate and the quality (contamination level) vary continuously so that the system design for downstream processes, if there is any, is complicated.

The recycle-and-bleed continuous operation, shown in Figure 11(b), has the advantage of a continuous, simple operation and is easily integrated with other processes. The disadvantages of this mode are that it is difficult to obtain a high product recovery and the system operates at the highest average

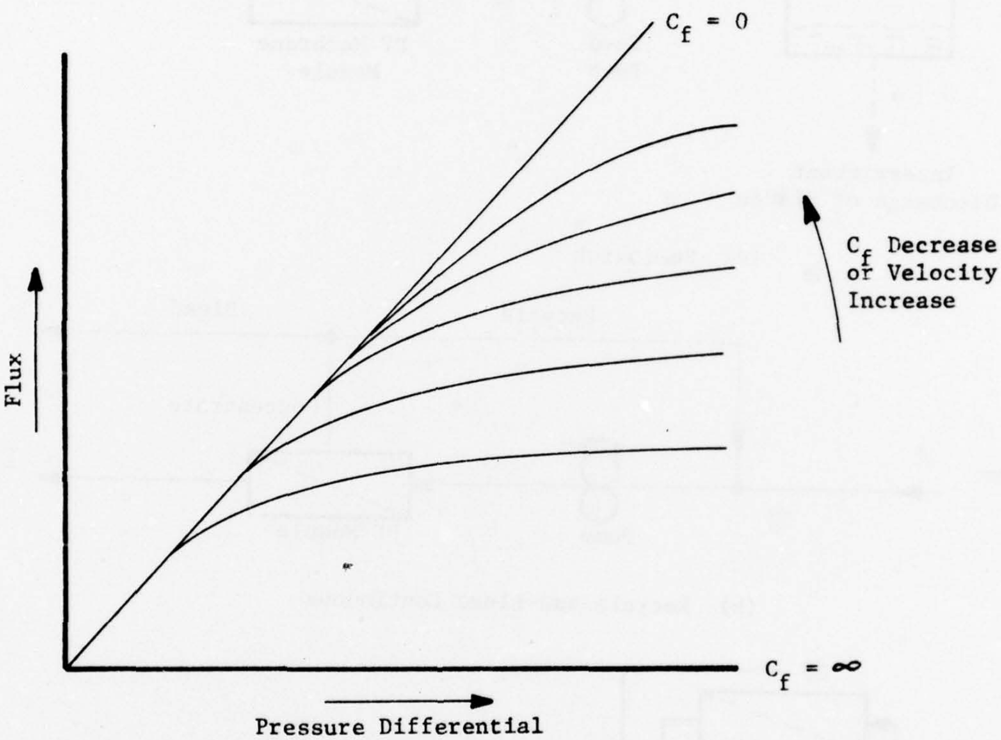
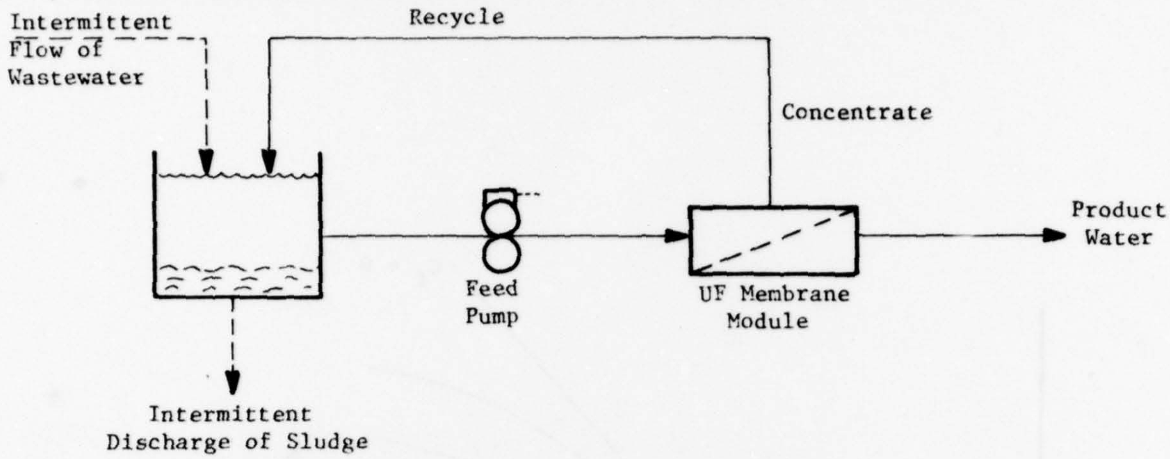
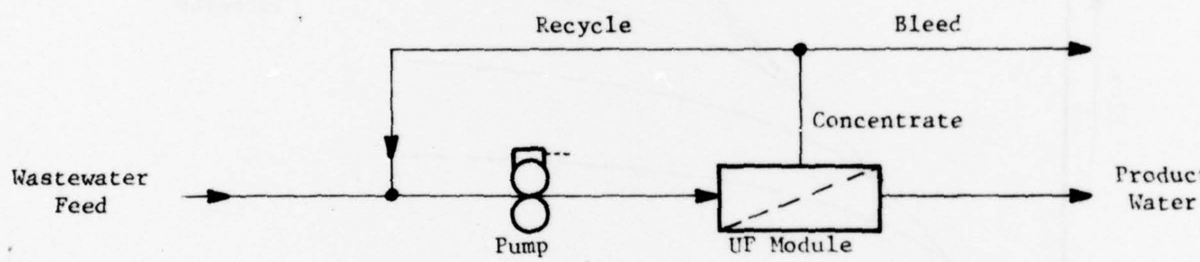


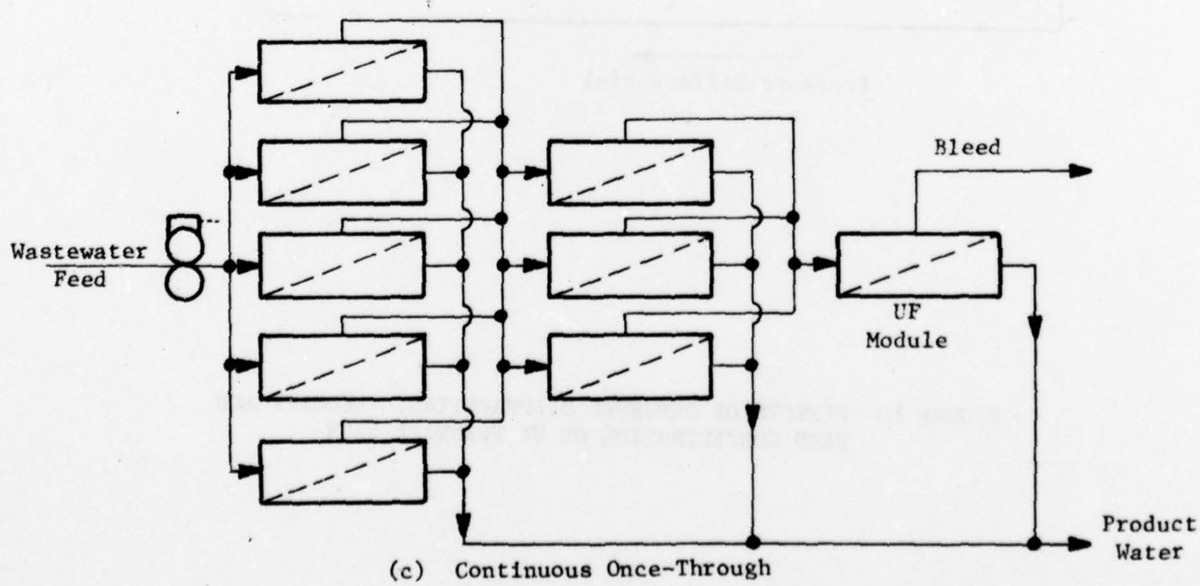
FIGURE 10 EFFECTS OF PRESSURE DIFFERENTIAL, VELOCITY AND FEED CONCENTRATION ON UF PERMEATE FLUX



(a) Semibatch



(b) Recycle-and-Bleed Continuous



(c) Continuous Once-Through

concentration level of the three modes. Thus the average flux and rejection is low relative to those of other modes.

The continuous once-through operation, shown in Figure 11(c), combines some of the advantages of both the semibatch and the recycle-and-bleed modes of operation. The feed passes once through each module in a single-pass which minimizes the average feed concentration and achieves maximum utilization of the modules in terms of flux and rejection. In addition, operation is continuous and a high product recovery can be obtained. The only drawback of this mode is that downstream modules continuously exposed to the high concentration of solutes are subject to more frequent fouling and thus more frequent maintenance. This mode of operation is recommended for sufficiently large installations.

With the above considerations in mind a unique process scheme was designed for the WTU. The WTU ultrafiltration process shown in Figure 12 combines the advantages of both the semibatch and the recycle-and-bleed modes of operation discussed above. Since the WTU is a rather small system, the continuous once-through operation was ruled out due to the requirements for complex plumbing, a larger pumping system and frequent maintenance. Most of the concentrate flow is recycled back to the pump suction so heat losses and heating requirements (shower and kitchen wastes are treated at 125 F are minimized. In order to achieve a high product recovery of 95%, the bleed stream of the concentrate was returned to the mixing zone of the equalization tank and sludge was removed from the clarifier. The permeate flow was intermittently recycled back to the UF feed tank so the downstream processes during the integrated operation could be operated at a constant flow rate with a reasonably sized permeate receiving tank. The ON/OFF operation of the high flow pump for the continuous, constant flow operation of the subsequent processes was not desired.

Selection of Operating Conditions

Most of the WTU operating conditions were dictated by the performance characteristics of the UF membranes selected. Within the range of volume, weight and power requirements specified in Table 5, the UF membrane flux and power consumption were of primary importance. Selection of the WTU operating conditions was largely based on the performance data of the UF membranes published by the manufacturer.[2]

Recycle Flow Rate

As pointed out previously, the flow velocity through the UF membranes had a significant effect on the membrane flux in a gel-layer mass transfer controlled operation. As the flow velocity increased, the flux increased. Consequently, the volume and weight of the membrane separation system required for a given capacity decreased. However, at higher velocities a larger pumping system and more power was required. The optimum flow rate should be determined by a trade-off between membrane costs on one hand and costs of pump and power on the other hand.

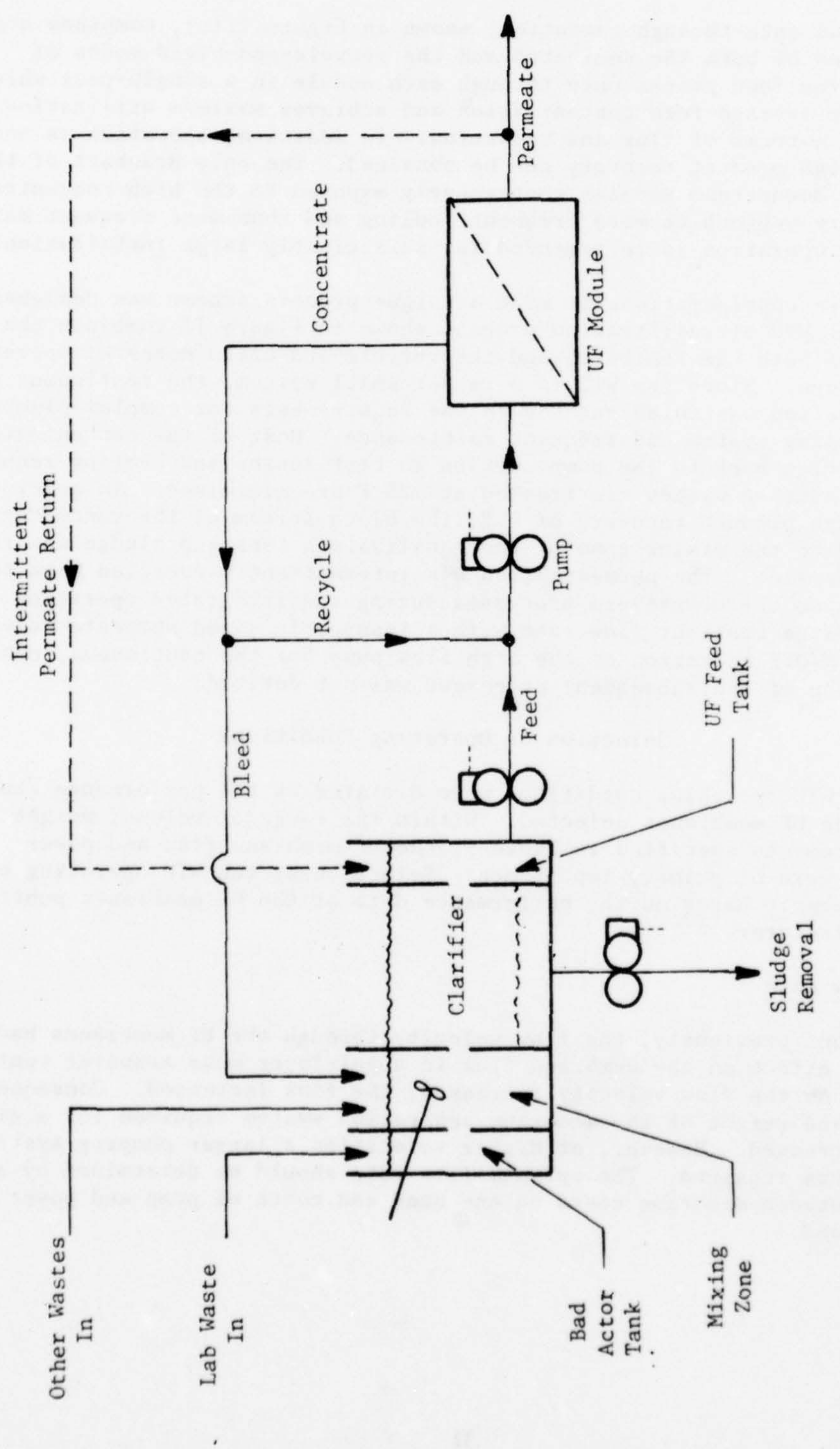


FIGURE 12 ULTRAFILTRATION PROCESS DIAGRAM

The permeate flux data by Gollan[2] of the hospital composite wastewater through the membranes are plotted in Figure 13 as a function of flow velocity. A significant increase of flux with an increase of velocity indicates that the UF membrane operates in the concentration polarization zone. A flow velocity of 17.4 ft/sec was selected to give the optimum balance between system volume and power requirements. Reynolds Number at that velocity is approximately 1.65×10^5 and the total flow rate of wastewater through 72 membranes (nine modules in parallel with eight membranes in series for each module) is 270 gpm. The recycle flow rate of the concentrate stream is then 250 gpm, since the UF feed flow rate is 20 gpm.

Pressure

Table 7 lists data collected to assess the effect of operating pressure on membrane flux.[2] Permeate flux was monitored on eight tubular membranes arranged in series. Pressure of the permeate stream was maintained at atmospheric pressure. As would be expected for UF operation in the concentration-polarization-limited regime, permeate flux is relatively insensitive to pressure differential for the range of pressures investigated. Therefore, the operating pressure at the inlet of the UF membrane assembly is set at 50 psig.

Temperature

As UF processing continues the permeate flux declines due to the solid concentration build-up in the feed and the increased concentration polarization on the membrane surface. In order to maintain relatively uniform fluxes, two process control schemes may be considered: (1) pressure control and (2) temperature control. As pointed out above, the pressure is rather insensitive to the flux in the operating range of interest. On the other hand, the temperature has a marked influence on the flux variation. Therefore, the temperature is selected as a control variable to maintain a desired flux.

The volumetric conversion, C_v, is defined as

$$C_v = V_o/(V_o - V_p) \tag{4}$$

where V_o and V_p are the initial batch volume and the accumulated permeate volume, respectively. Thus, C_v = 20X represents 95% recovery of the feed wastewater as the permeate product.

Shower wastewater gives the lowest flux among various hospital wastes. The effect of temperature on the permeate flux of shower waste is presented in Figure 14. The permeate flux was measured 20 hours after start of the total recycle tests. As the temperature increases, the flux increases very rapidly. The higher flux at higher temperature may be attributed to the reduced water viscosity (see Equation 3) and probably to the reduced membrane fouling.[2]

Curve (b) in Figure 14 indicates a conservative estimate for the permeate flux after 95% product recovery (C_v = 20X). Since the flux should be at least 30 gal/ft^2/day at all times, shower waste should be processed at elevated

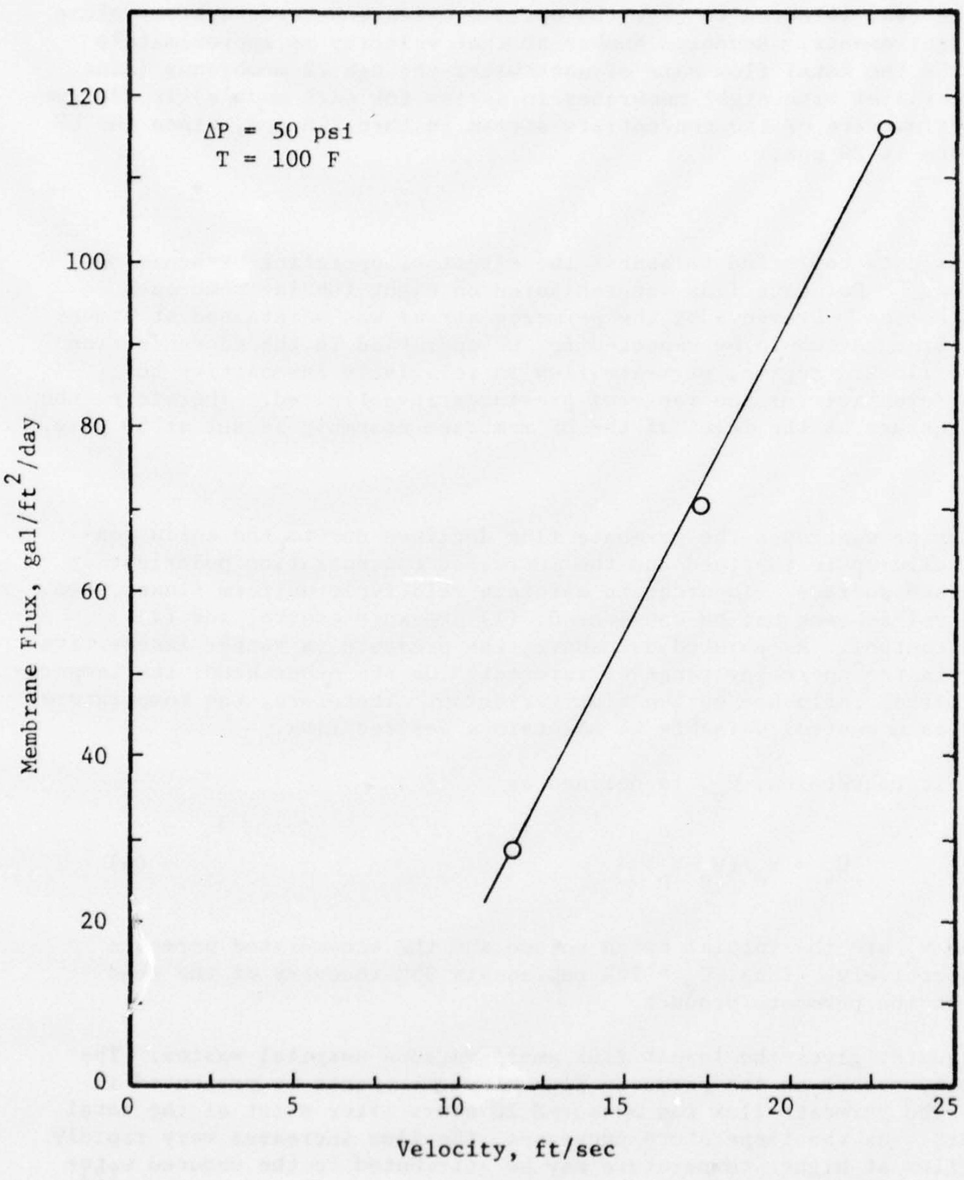


FIGURE 13 EFFECT OF FLOW VELOCITY ON UF PERMEATE FLUX FOR HOSPITAL COMPOSITE WASTEWATER

TABLE 7 PERMEATE FLUX AT VARIOUS FEED PRESSURES[a]

MUST Waste[b]	Tube Number/Inlet Pressure							
	1 50 psig	2 48 psig	3 46.5 psig	4 45 psig	5 43 psig	6 41 psig	7 39.5 psig	8 38 psig
Operating Room	51.3	44.3	42.5	40.8	41.9	53.6	51.3	65.2
Kitchen	48.3	47.8	44.3	48.9	45.4	43.1	43.1	38.4
Shower	37.5	36.3	36.9	33.4	35.4	38.1	38.1	45.0

(a) $gal/ft^2/day$
(b) Total recycle experiments at C_v = 5X

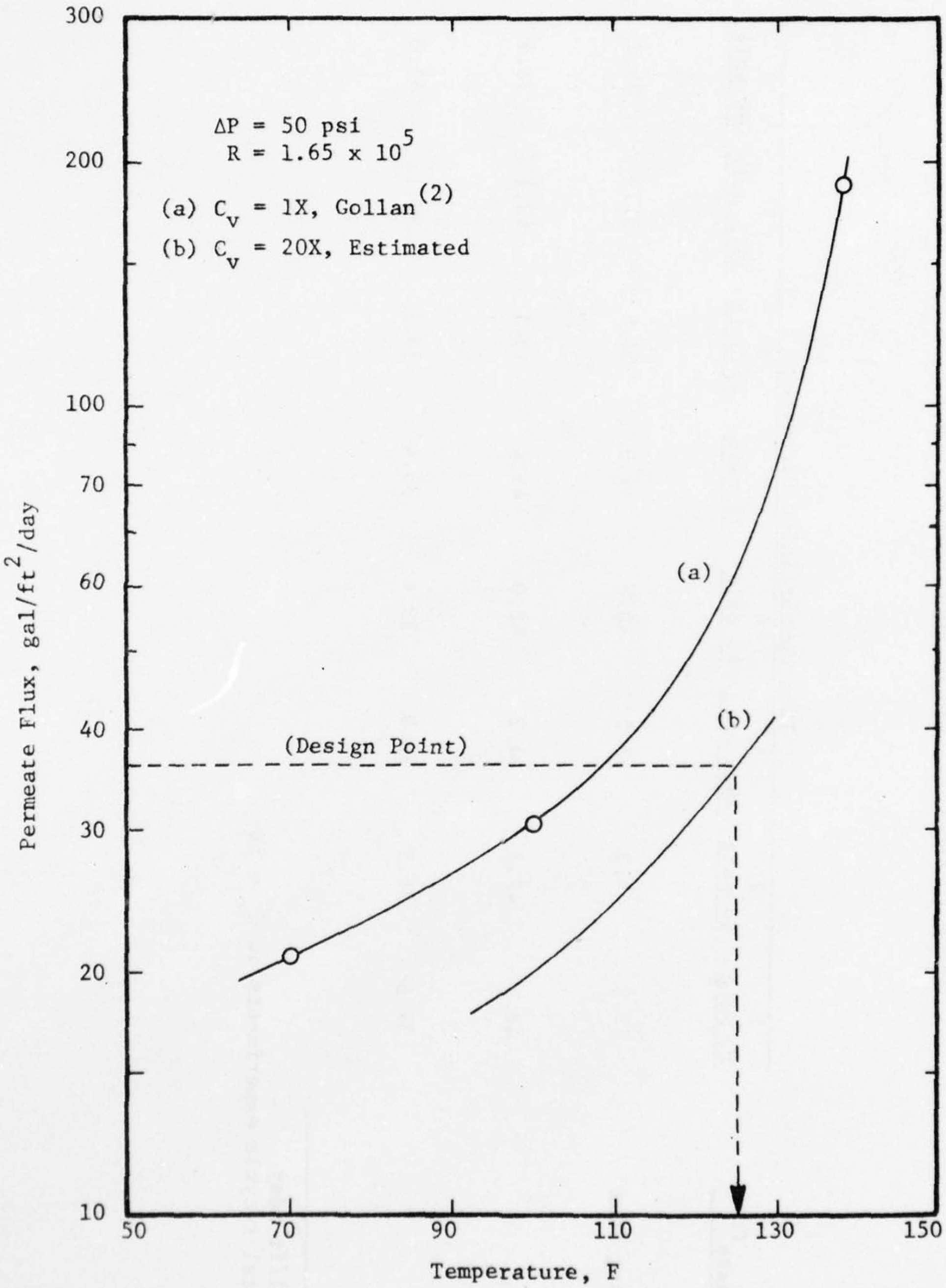


FIGURE 14 EFFECT OF TEMPERATURE ON UF PERMEATE FLUX FOR SHOWER WASTE

temperature. An operating temperature of 125 F near the end of 20-hour operation was selected to obtain a flux of 36 gal/ft^2/day.

Kitchen waste has a similar flux variation as the shower waste. Due to the higher fluxes at the ambient temperature, other wastes can be processed without heating. Projected temperature and flux variations for shower and kitchen wastes were presented in Figure 15. In order to save energy for both heating in the UF and cooling in the RO process, the heater is turned on approximately five hours after the start of operation. The temperature is raised gradually to 125 F near the end of a 20-hour operation. Other wastewaters are planned to be processed at the ambient temperature without control. In the prototype design of the WPS, it is desired to implement a feedback control system of temperature with measurements of permeate fluxes.

pH of Wastewater

In order to maintain the pH of the UF permeate within the allowable range for RO membranes (pH = 5-9 for Du Pont B-10 membrane), pH adjustment either before or after the UF assembly is required for certain wastes. Since pH adjustment can induce precipitation, pH of the wastewater is adjusted to 8.0 - 8.5 in the EP tank so that any precipitated solids can be removed prior to RO. The pH adjustments reduce the fluxes due to the increased concentration of suspended solids but the rejection efficiencies of contaminants increase. The lower flux of the pH adjusted wastes is still acceptable.

Contaminant Removal Efficiencies of UF Membrane

The contaminant removal efficiencies of the UF membranes(2) are summarized below for the hospital composite wastewater:

Contaminant	Feed Conc., mg/l	Membrane Rejection, %
Suspended Solids	70 - 12,200	99.9
Turbidity	210 - 5,000 JTU	99.6
Total Solids	1,240 - 37,200	26 - 57
TOC	350 - 12,300	70 - 89
COD	1,270 - 44,600	67 - 90

The above results were obtained with the HFD tubular membrane operated at a flow velocity of 11.5 to 23.3 ft/sec, a temperature of 100 F and a feed pressure of 65 psia. The system was operated in a semibatch mode to C_v = 50X. Almost complete removal of suspended solids and turbidity was noted.

Projected Performance of the WTU

A simplified model was developed to characterize the WTU performance. Overall material balances were used to derive mathematical expressions for the concentration variations of a certain contaminant in the system. The overall process of the WTU was modeled as a semibatch operation (one batch per day).

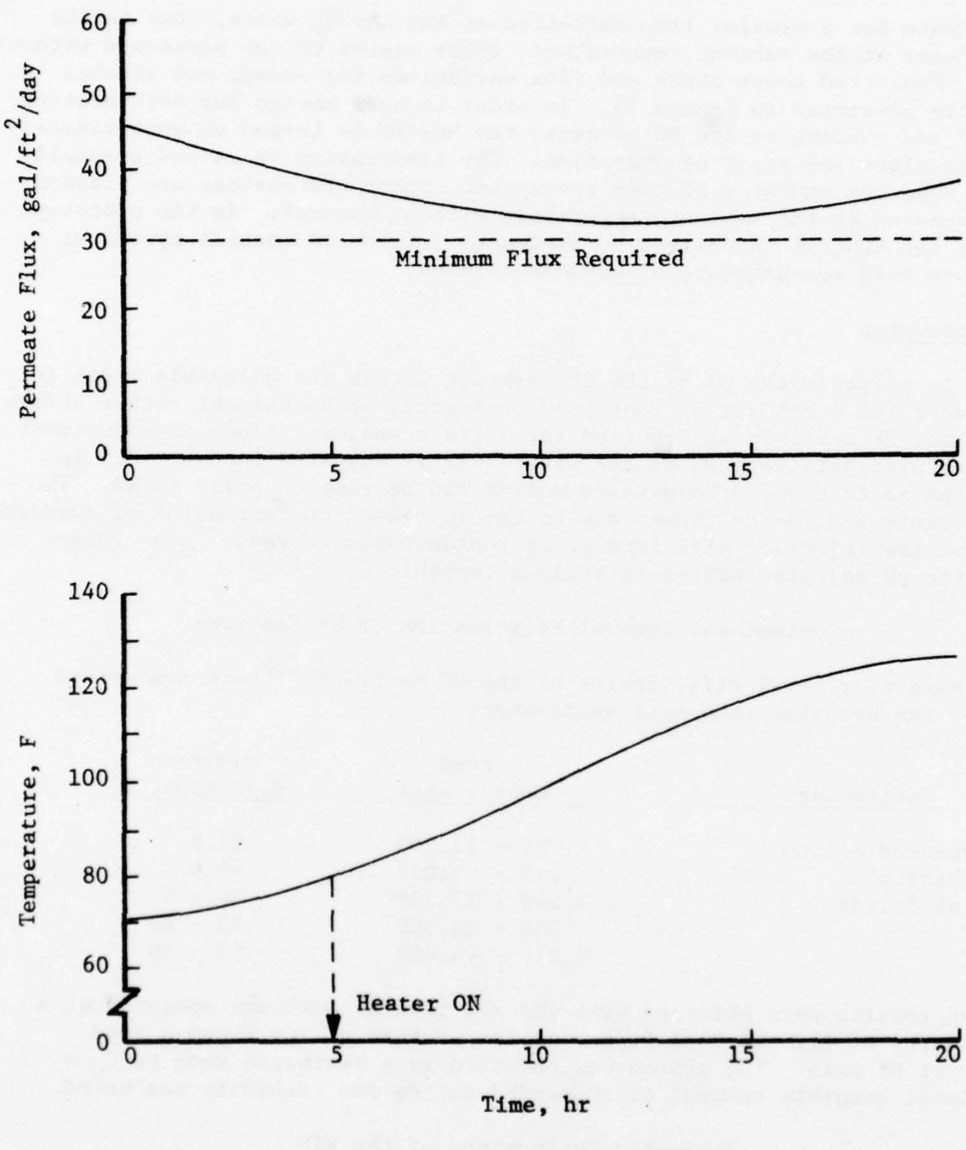


FIGURE 15 TEMPERATURE PROGRAMMING FOR SHOWER AND KITCHEN WASTES

For the nth day of operation (nth batch) the overall material balances for water and contaminants produce the following equations for a 95% product recovery and an initial charge of 412 gal:

$$R_o^{(n)} = 0.55BR_m + 0.95BR_m(1-R_m)A^{n-1} \quad (5)$$

$$C_s^{(n)}/C_i = B(1.5 + 9.5R_m) - 10.45BR_mA^n \quad (6)$$

where

$R_o^{(n)}$ = the overall contaminant removal efficiency of the system for the nth batch,

C_s = contaminant concentration in the system,

C_i = contaminant concentration in the wastewater influent,

R_m = UF membrane rejection,

$$B = 1/(1.5 - 0.95R_m), \quad (7)$$

$$A = 0.0909 + 0.576R_m. \quad (8)$$

As n approaches infinity, it follows from Equations 5 and 6 that

$$R_o = 0.55R_m/(1.5 - 0.95R_m) \quad (9)$$

$$C_s/C_i = (1.5 + 9.5R_m)/(1.5 - 0.95R_m) \quad (10)$$

By using these equations, the overall contaminant removal efficiencies and the contaminant concentration in the system (feed to the UF membranes) were calculated from membrane rejection data. The results are presented in Table 8. Significant decreases in the removal efficiencies of total solids, TOC and COD are noted.

The contaminant removal efficiencies of the WTU vary depending on the membrane rejection and the amount of initial charge to the EP tank. The removal efficiencies increase with a decrease of the initial charge. On the other hand, the permeate flux decreases since the contaminant concentration builds up in the system. The projected removal efficiencies in the WTU operating range are approximately 99% for suspended solids and turbidity, 70 to 80% for TOC and COD and 26% for total solids. The contaminant concentration in the system would vary from 6 to 20 times the feed concentration in the wastewater influent.

TABLE 8 PROJECTED PERFORMANCE OF THE WTU[a]

Contaminant	Membrane Rejection, R_m	System Efficiency, R_o	C_s/C_i
Suspended Solids	0.999	0.997	19.9
Turbidity	0.996	0.989	19.8
Total Solids	0.50	0.26	6.1
TOC	0.88	0.73	14.8
COD	0.90	0.76	15.6

(a) Basis: 95% Product Water Recovery and 412 gal initial charge to the EP tank.

Component Design

Equalization/Prescreening Tank

The function of the EP tank is to (a) remove by settling and screening all large influent wastewater solids (i.e., bandages, organs, bones, fragments, paper, waste food, etc.), (b) equalize the hydraulic loading variations to result in a constant flow to the UF unit process and (c) dampen the refractory organics and biological loading fluctuations to result in a more uniform feed to the UF unit process.

Figure 16 shows a comparison of the cumulative volumetric flows into and out of the EP tank according to the simplified flow schedule presented in Figure 9. Regular scheduled maintenance time falls between 0 and 4 hours in this 24-hour operation cycle. The time average flow from the EP tank is assumed to be constant at 3.5 gpm. Figure 16 illustrates that a maximum excess capacity and excess hydraulic load of approximately 385 and 486 gal, respectively, exist. This suggests that to maintain a constant 3.5 gpm outflow from the equalization tank a minimum tank volume of 870 gal is required. This size tank would not include any safety factor; i.e., at some time during a 24-hour cycle the tank will be filled to capacity and at some other time, empty. An additional volume of 420 gal (2-hour reserve) was added to the 870 gal to dampen drastic variations of contaminant concentrations. A minimum wetted volume of 1,290 gal was specified. Because of the way the EP tank is constructed with the "bad actor" compartment, mixing compartment, clarifier/grit compartment and UF feed tank interconnected under normal operation, the actual tank total volume is equal to 1,321 gal. A sketch of the tank design is shown in Figure 17. The volume breakdown is shown below:

Compartment		Wet Volume, gal
Bad Actor		224
Mixing		134
Clarifier/grit		883
UF feed		80
	Total	1,321

A pH monitor/controller and an agitator installed in the mixing compartment adjust the pH of wastewater to approximately 8. The pH adjustment induces precipitation of some dissolved solutes and increases the contaminant removal rate of UF and RO membranes.

A sludge pump is provided to remove the settled material (sludge) from the base of the tank. The sludge is scheduled to be removed automatically once each day during the four-hour maintenance period. This sludge pump down (flush) cycle is designed for 11 gpm and scheduled for 12 minutes. A drain valve is provided for rapid drainage of the tank to the environment. The drain line is sized at 3 in for drainage of a full tank in 24 minutes. A high and low level monitor is needed to alert the operator to extreme tank level conditions. The control valve between the EP tank and UF feed tank is normally open. The valve is only closed during a UF cleaning cycle. The turbidity and temperature sensors are installed for scientific data collection.

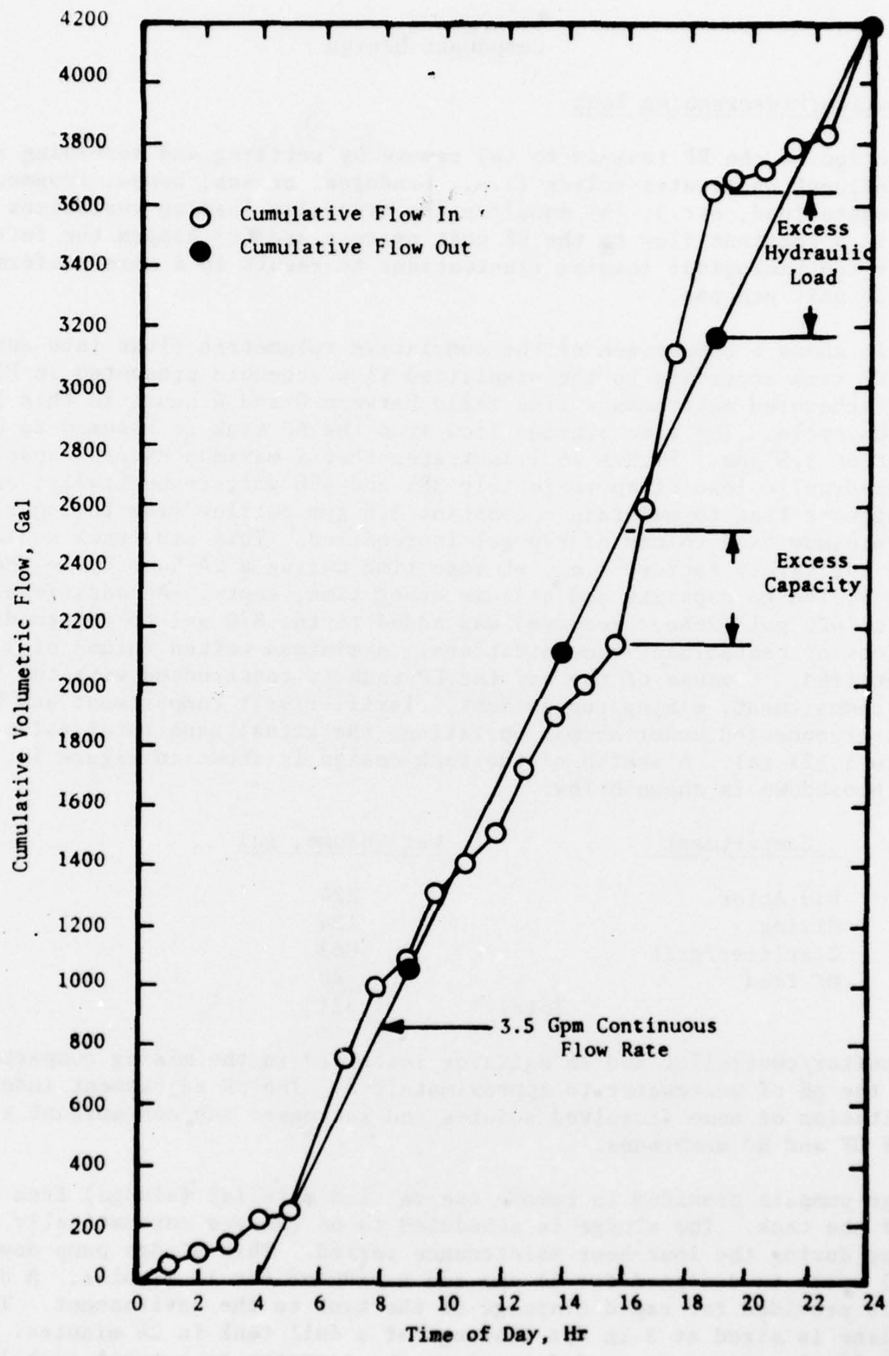


FIGURE 16 A COMPARISON OF THE FLOWS INTO AND OUT OF THE EQUALIZATION TANK (12)

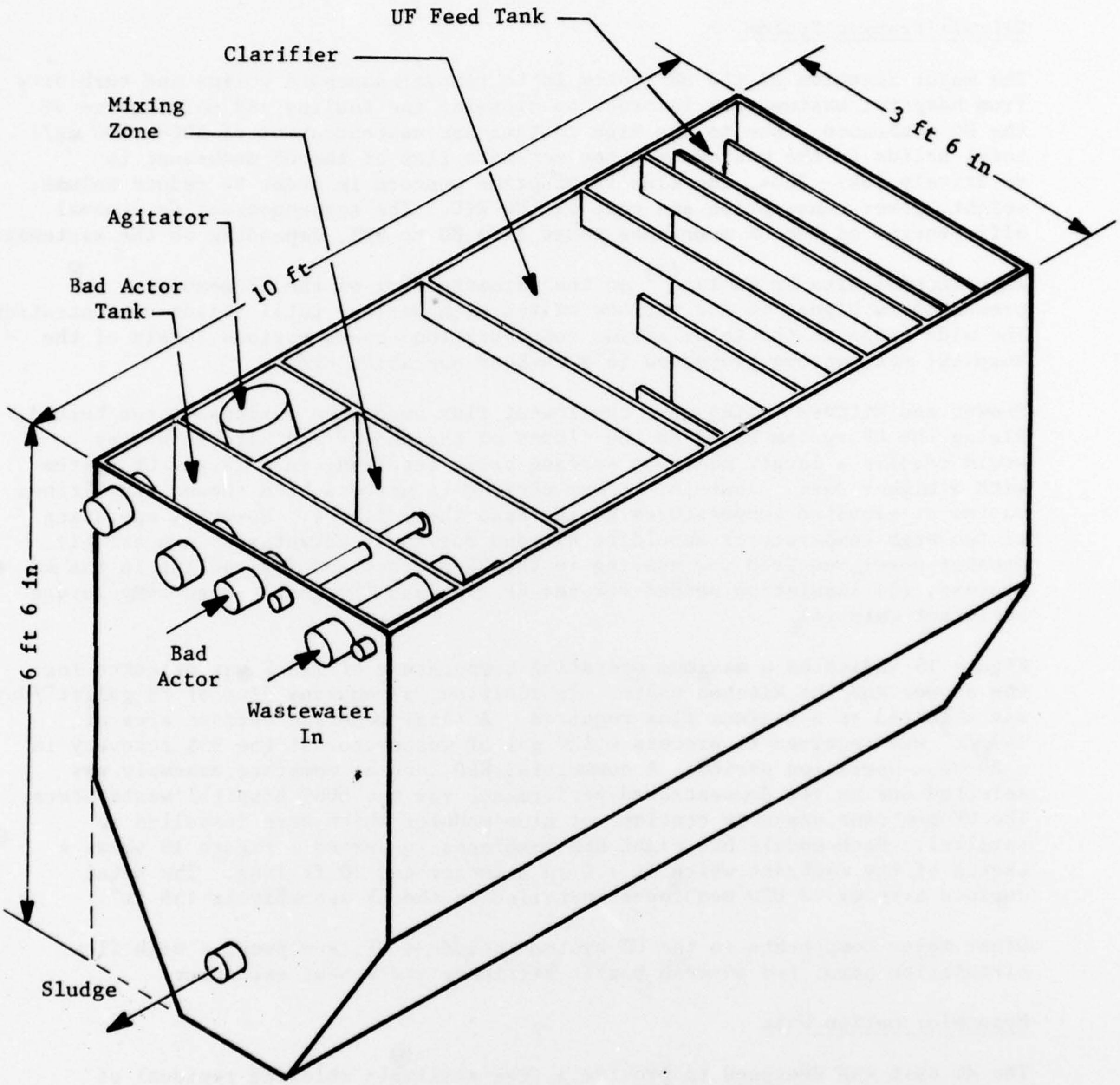


FIGURE 17 EQUALIZATION TANK

Ultrafiltration System

The major function of the UF system is to remove suspended solids and turbidity from hospital wastewaters in order to minimize the fouling and maintenance of the RO membranes. Due to the high contaminant concentration of 500-4,200 mg/l total solids in the wastewater, the permeate flux of the UF membranes is relatively low. Thus, the flux is of prime concern in order to reduce volume, weight, power consumption and cost of the WTU. The suspended solids removal efficiencies of the UF membranes range from 80 to 99%, depending on the wastewater.

Experimental data by Gollan[2] on the permeate flux of the UF membranes are presented in Figure 18 for various wastes with various total solids concentrations. The wide range of the total solids concentration covers various levels of the hospital wastewaters projected in a 24-hour operation cycle.

Shower and kitchen wastes gave the lowest flux among the various wastes tested. Sizing the UF system based on the fluxes of the shower and kitchen wastes would require a larger membrane surface area, resulting in a larger UF system with a higher cost. Instead, it was decided to process both shower and kitchen wastes at elevated temperatures to increase their fluxes. However, operating at too high temperatures should be avoided due to disadvantages such as: (1) greater power required for heating in the UF process and for cooling in the RO process, (2) insulation needed for the EP tank and (3) costly high temperature resistant material.

Figure 15 indicates a maximum operating temperature of 125 F was selected for the shower and the kitchen waste. In addition, a membrane flux of 33 gal/ft^2/day was selected as a minimum flux required. A total membrane surface area of 143 ft^2 was required to process 4,120 gal of wastewater at the 95% recovery in a 20-hour operation period. A commercial HFD tubular membrane assembly was selected due to its demonstrated performance for the MUST hospital wastewaters. The UF membrane assembly consists of nine modules which were installed in parallel. Each module has eight HFD membranes in series. Figure 19 shows a sketch of the membrane which is 1.0 in diameter and 10 ft long. The total surface area of 72 HFD membranes installed in the UF assembly is 158 ft^2.

Other major components in the UF system include a UF feed pump, a high flow circulation pump, two 40-mesh basket strainers and a heat exchanger.

Hypochlorination Unit

The HC unit was designed to provide a free-available chlorine residual of 2 mg/l in the product water for surface discharge. The HC unit consists of a hypochlorite storage tank, a hypochlorite feed pump and static mixers. The storage tank, constructed of polyethylene, contains 50 gal of hypochlorite solution. The pump has variable speeds to permit control of the hypochlorite dose rate. Three 1.5 in diameter PVC static mixers were installed in series to mix the discharge water with the hypochlorite solution.

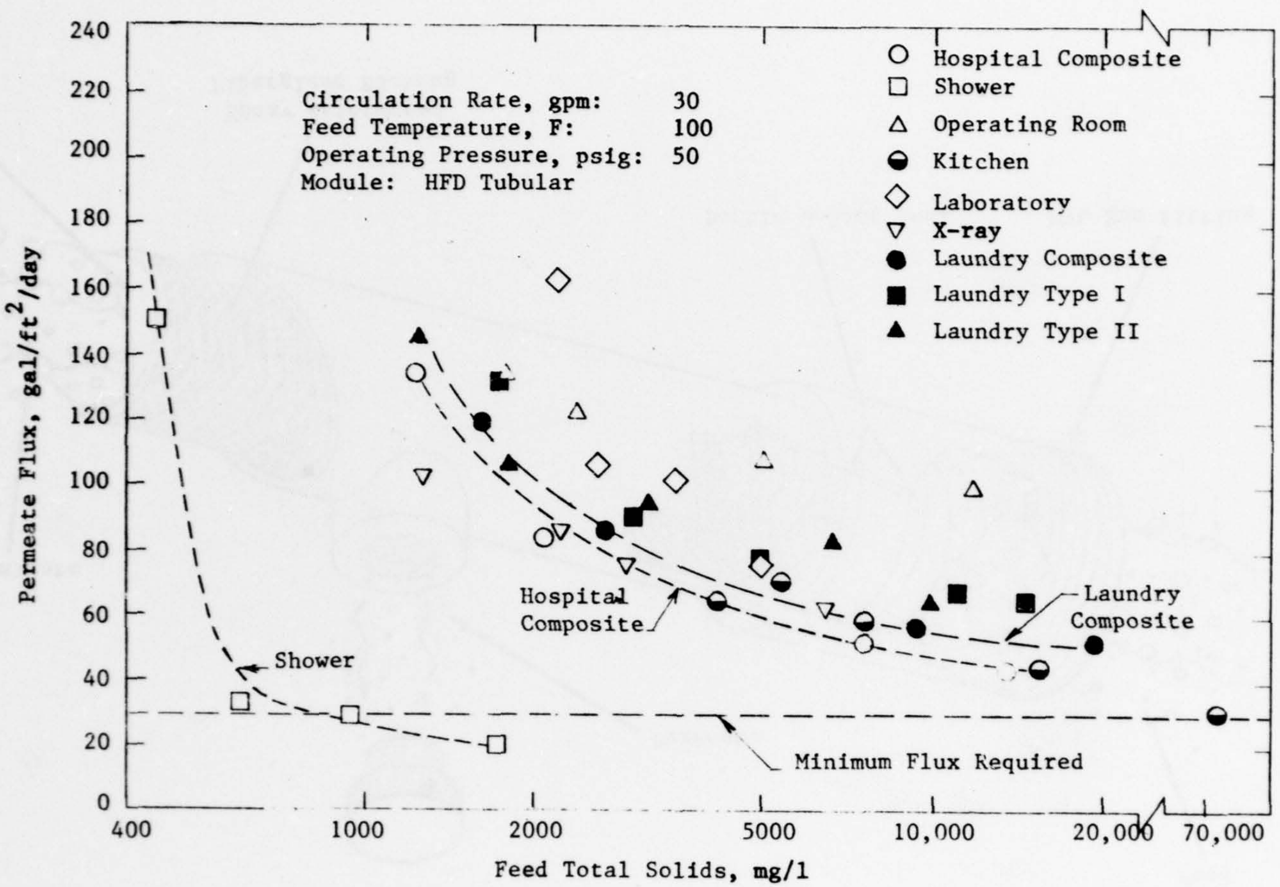


FIGURE 18 FLUX VERSUS TOTAL SOLIDS CONCENTRATION OF FEED FOR VARIOUS INDIVIDUAL AND COMPOSITE WASTES(2)

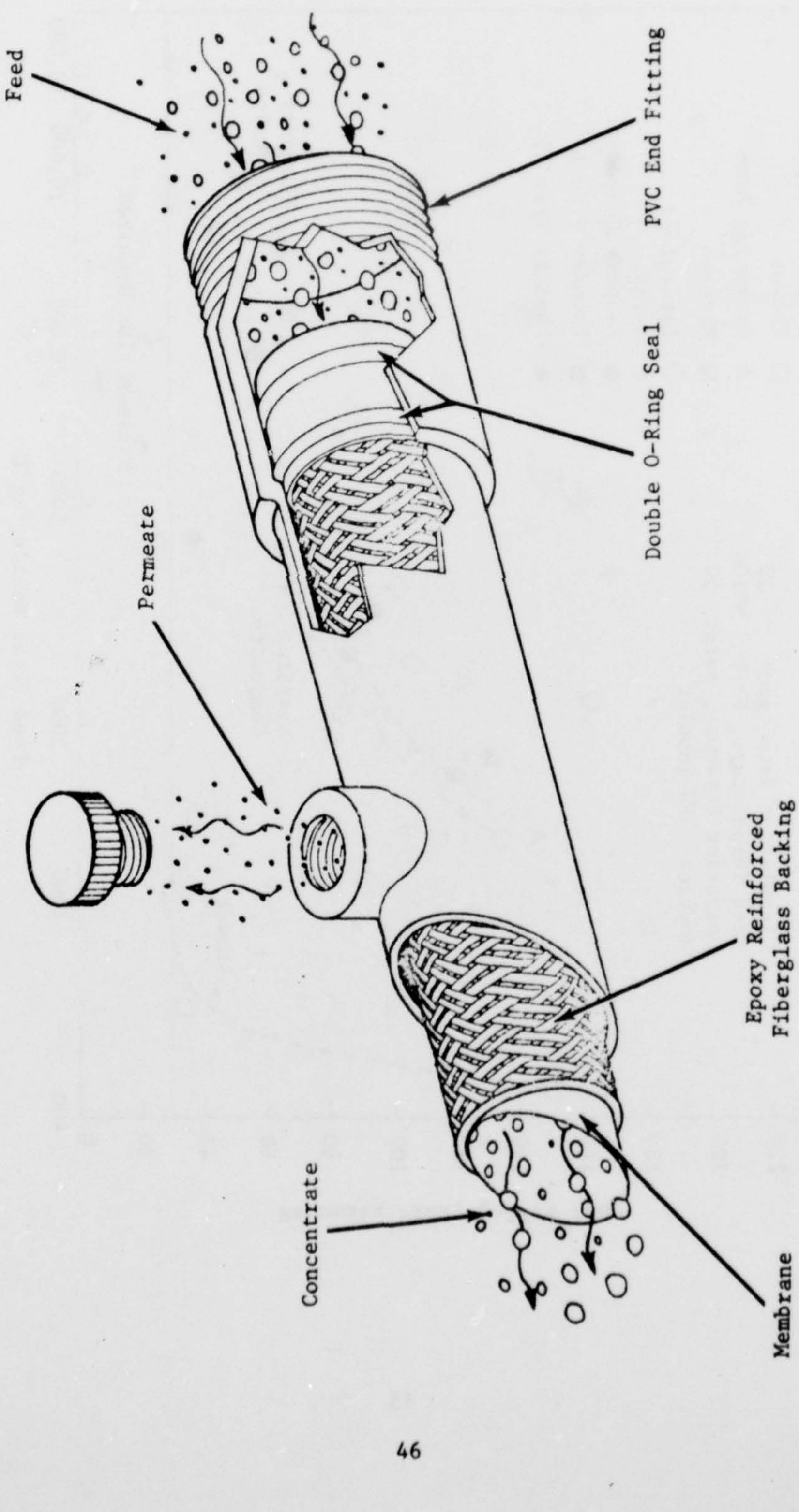


FIGURE 19 ULTRAFILTRATION MEMBRANE

In order to maintain a constant level of free-available chlorine residual, the hypochlorite dose rate should be determined by the chlorine demand and the flow rate of the UF permeate. The chlorine demand of the UF permeate varies depending on the wastewater source. The chlorine dosage control on the WTU front panel has six ranges of the hypochlorite feed flow rate which are manually adjusted according to the wastewater source. Once the chlorine dosage control is set the hypochlorite dose rate is automatically controlled in a feed-forward mode by the output of a flow sensor located in the UF permeate stream.

Control/Monitor Instrumentation

Both automatic and semiautomatic instrumentations were incorporated into the WTU design to control and monitor system performance. Only the semiautomatic instrumentation will be described in this section. Detailed descriptions of the automatic instrumentation can be found elsewhere.[6,7] The objective of the semiautomatic instrumentation was to provide a pilot testing capability for evaluation of the WTU performance.

Control Features

The following control features were incorporated:

1. Automatic fail-safe shutdown initiated by five alarm conditions (Table 3)

2. Automatic Temperature Control

3. Automatic pH control

4. UF circulation flow rate manually set by a digital potentiometer

5. Six ranges of the hypochlorite feed rate manually selected by a chlorine dosage switch on the front panel

6. The chlorine dose rate automatically controlled in a feed-forward mode according to the water flow rate.

7. A total of 18 setpoints manually set on the digital potentiometers to define warning, alarm and operating conditions

Monitor Features

The following monitor features were incorporated in the WTU:

1. Water level in the EP and UF tanks

2. pH of wastewater in the EP tank and UF feed

3. Temperature of wastewater in the EP tank and UF feed

4. Turbidity of wastewater in the EP tank and UF feed

5. Pressure of the wastewater feed to UF membranes

6. Pressure drops across the basket strainers and UF membrane assembly

7. Flow rates of the recycle and the permeate stream in UF system

8. Accumulated total flow of UF permeate

9. Ten light indicators provided warning and alarm conditions

CONCLUSIONS

The following conclusions were drawn from this development program:

1. The concept of the integrated, transportable WPS is a viable solution to meet the needs for the multipurpose water treatments in the field Army medical facilities.

2. The WTU is capable of treating the nonsanitary hospital wastewaters for a safe discharge to the environment and providing a suitable pretreatment for the reuse water production from the hospital wastewaters. This is accomplished by the use of three unit processes: equalization/prescreening, ultrafiltration and hypochlorination.

3. The prototype WTU can be housed in a standard ward container for transportation via conventional routes, such as standard cargo trucks, external helicopter loads, railroad, ship or cargo aircraft.

4. The semiautomatic instrumentation and a number of flexibilities enable the WTU to serve as a test bed for the purpose of general water treatment process evaluations.

RECOMMENDATIONS

The following recommendations are direct results of this study:

1. Integrated testing of the WPS with simulated hospital wastewaters should be performed to evaluate and characterize the performances of the WTU and the WPS.

2. In addition to the hospital wastewater treatment, the WTU should be used as a flexible test bed to evaluate the treatability of various kinds of wastewaters generated in other Army installations.

3. An optimization study for a prototype WTU is recommended to further reduce the volume and weight of the WTU. The WTU is the largest among the three units of the WPS.

4. The semiautomatic instrumentation and other flexibilities of the WPS pilot plant should be eliminated in the prototype system design.

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APPENDIX 1 COMPOSITIONS OF SIMULATED HOSPITAL WASTEWATERS

Wastewater	Constituent	Concentration	
Shower	Hair Oil	150	mg/l
	Shower/Lavatory Cleaner	100	mg/l
	Sodium Chloride	83	mg/l
	Soap	69	mg/l
	Hair Gel	37	mg/l
	Toothpaste	37	mg/l
	Talc	20	mg/l
	Soil (Kaolinite)	19	mg/l
	Hair	10	mg/l
	Hair Shampoo	5	mg/l
	Phisohex Soap	3	mg/l
	Mouthwash	2	mg/l
	DEET (Insect Repellent)	1	mg/l
	Deodorant	1	mg/l
	Hair Coloring	1	mg/l
	Hair Dye	1	mg/l
	Urea	1	mg/l
Operating Room	Haema-Sol	750	mg/l
	Betadine	722	mg/l
	Sodium Chloride	461	mg/l
	Hair	414	mg/l
	Wescodyne	136	mg/l
	Blood	360	µl/l
Kitchen	Detergent Type I (FSN7930-634-3935)	1890	mg/l
	Sparkleen	1510	mg/l
	Suspended Solids (Dog Food)	1200	mg/l
	Scouring Powder (FSN 7930-205-0442)	189	mg/l
	Vegetable Oil	150	mg/l
	Grease (Lard)	100	mg/l
	Hand Soap		
Laboratory[a]	Sparkleen	302	mg/l
	1 1/2% Thioglycolate	3.77	mg/l
	0.85% Sodium Chloride	3.62	mg/l
	Zinc Sulfate	2.49	mg/l
	Urine	2560	µl/l
	Blood	1060	µl/l
	Dichromare Cleaning Solution	755	µl/l

(a) Formula will undergo modification as part of USAMBRDL effort to reduce load on WPS through variations in MUST Medical Complex procedures, e.g., elimination of urine by pouring into a vat and then into the incinerator and elimination of methyl alcohol by (1) using prepared laboratory stain sets or (2) substitution with another alcohol (ethanol, propanol or isopropanol).

continued-

Appendix 1 - Continued

Wastewater	Constituent	Concentration	
Laboratory - continued	0.1N Sodium Hydroxide	272	µl/l
	1 1/2% Blood Agar	249	µl/l
	1 1/2% Chocolate Agar	249	µl/l
	1 1/2% EMB Agar	249	µl/l
	Methyl Alcohol	242	µl/l
	5% Phenol Solution	189	µl/l
	1 1/2% Agar	139	µl/l
	Giemsa Stain	90.6	µl/l
	Wright Stain	83.0	µl/l
	Acetone	75.5	µl/l
	0-Toluidine Reagent	41.5	µl/l
	Lysol (undiluted)	37.7	µl/l
	Biuret Reagent	22.6	µl/l
	Lithium Diluent	22.6	µl/l
	Phenol Color Reagent	18.9	µl/l
	Alkali-hypochlorite Reagent	15.1	µl/l
	Crystal Violet Stain	15.1	µl/l
	10% Formaldehyde	15.1	µl/l
	KI-I Solution	15.1	µl/l
	Safranin	15.1	µl/l
	22.2% Sodium Sulfate Solution	15.1	µl/l
	3% Sulfosalicylic Acid	15.1	µl/l
	30% Trichloracetic Acid	11.3	µl/l
	Buffered Substrate	7.55	µl/l
	Bilirubin Standard	7.55	µl/l
	2% Sodium Citrate Solution	7.55	µl/l
	Diazo Reagent	7.55	µl/l
	DNPH Color Developer	7.55	µl/l
	Ether	7.55	µl/l
	Immersion Oil	7.55	µl/l
	Spinal Fluid	7.55	µl/l
X-ray[a]	Silver Chloride	215	mg/l
	Phisohex Soap	214	mg/l
	Kodak X-Omat Developer	28.3	ml/l
	Kodak X-Omat Fixer	28.3	ml/l
Laundry Type I	Detergent Type I (FSN 7930-634-3935)	650	mg/l
	Alkalinity	500	mg/l
	Oil and Grease (Vegetable Oil)	200	mg/l
	Kaolinite Clay	150	mg/l

(a) X-ray waste may eventually be eliminated when the dry X-ray becomes standard military procedure.

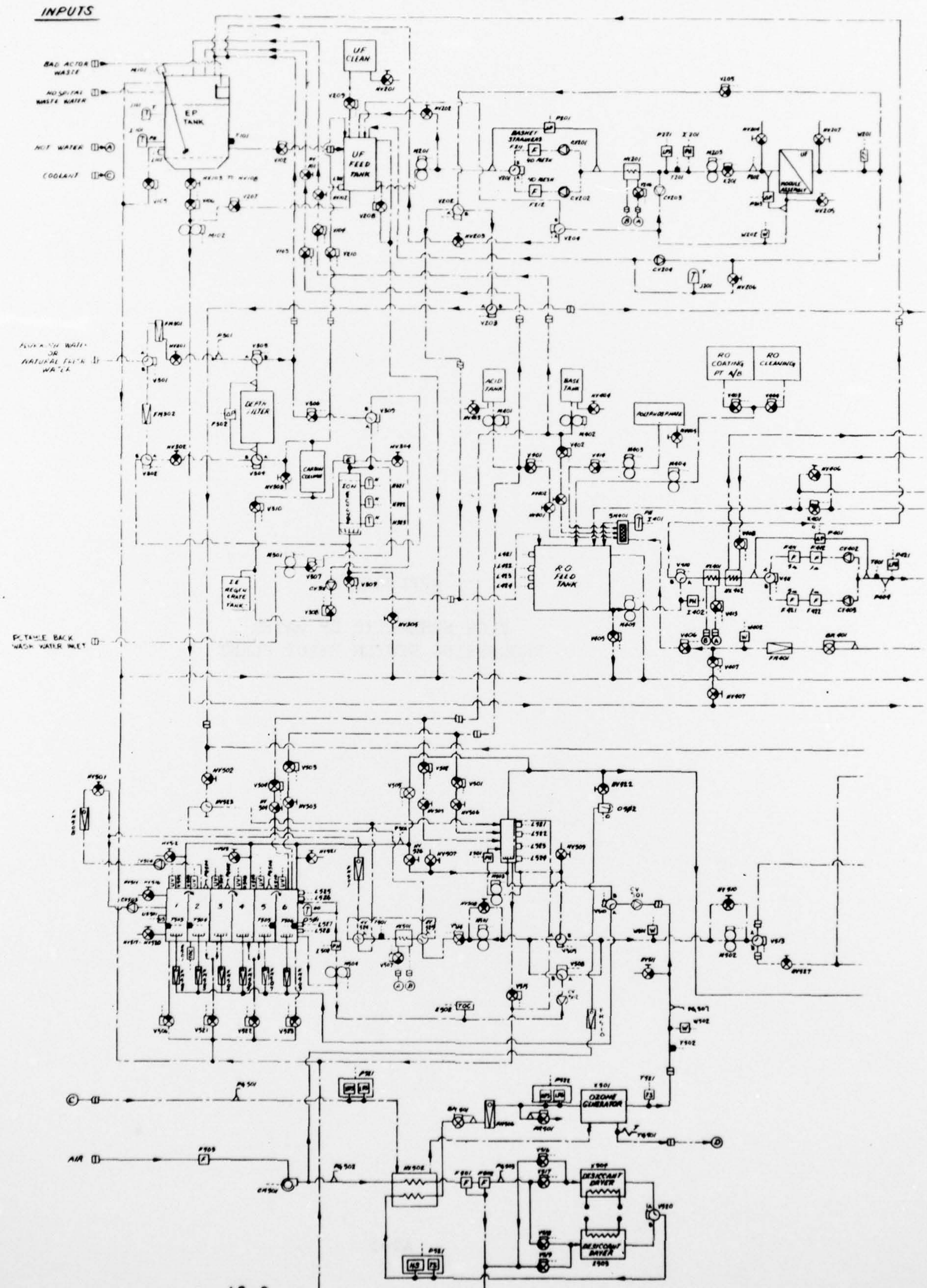
continued-

Appendix 1 - Continued

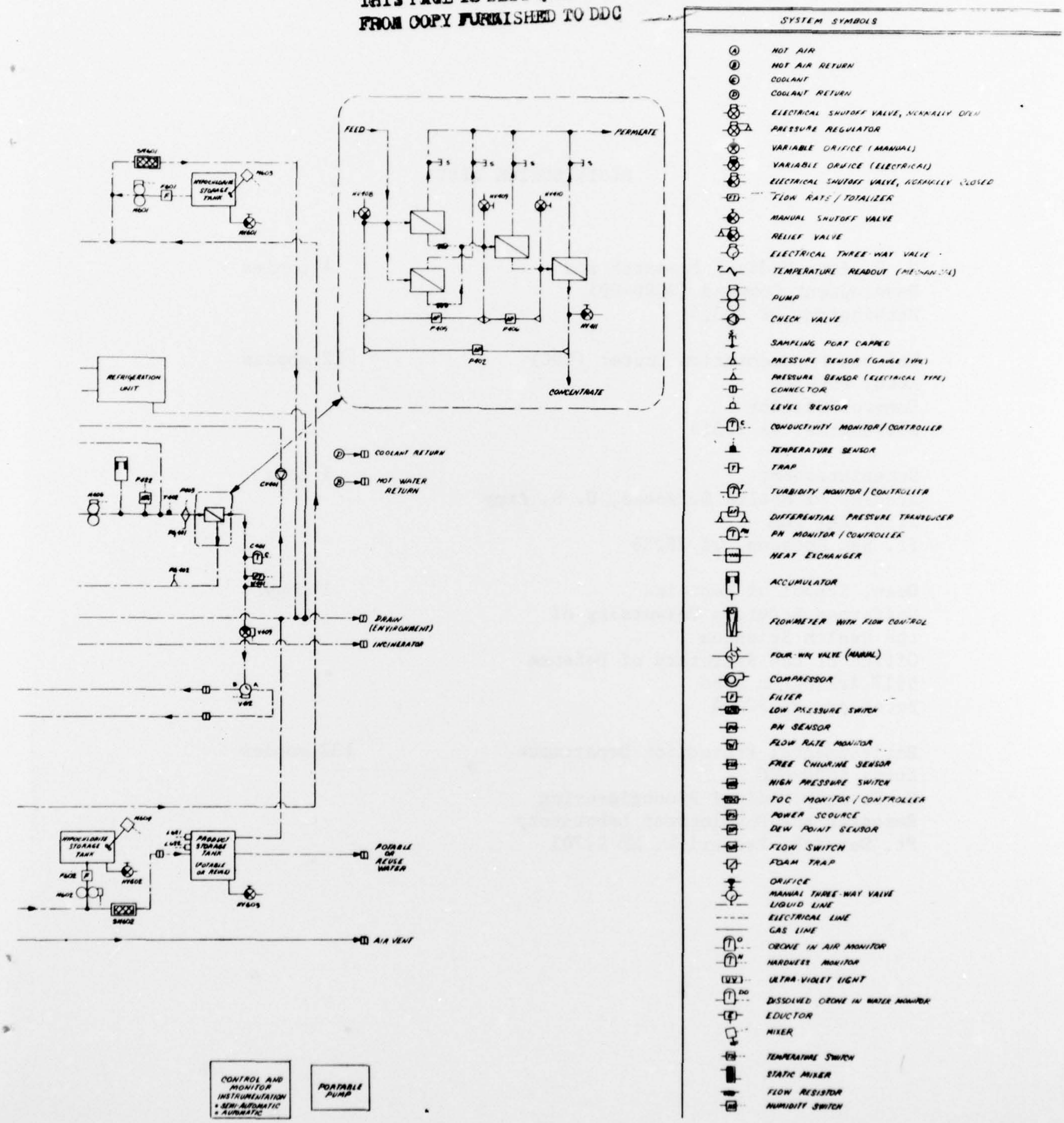
Wastewater	Constituent	Concentration	
Laundry Type I	Sour (Downey Fabric Softener)	116	mg/l
	Urea	20	mg/l
	DEET	19	mg/l
	Blood	874	μl/l
Laundry Type II	Detergent Type II (FSN 7930-664-0337)	518	mg/l
	Alkalinity	500	mg/l
	Sour	116	mg/l
	Kaolinite Clay	100	mg/l
	Oil and Grease (Vegetable Oil)	100	mg/l

APPENDIX 2

FLOW SCHEMATIC OF WATER
PROCESSING SYSTEM PILOT PLANT


INPUTS
BAD ACTOR WASTE
HOSPITAL WASTE WATER
HOT WATER
COOLANT
EP TANK
UF CLEAN
UF FEED TANK
BASKET STRAINERS
DEPTH FILTER
CARBON COLUMN
ACID TANK
BASE TANK
RO COATING PT A/B
RO CLEANING
RO FEED TANK
POTABLE BACK WASH WATER INLET
OZONE GENERATOR
DESICCANT DRYER
AIR

OUTPUTS



NOTE: 1) SAMPLE VALVES SHOWN AT THE TOP AND BOTTOM OF STAGE 1 OF THE OZONE CONTACTOR ARE ON ALL STAGES BUT NOT SHOWN FOR SIMPLICITY.

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